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Patterns of Public-Sector and Private-Sector Patenting in Agricultural Biotechnology

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Over the past 20 years, patenting in agricultural biotechnology has grown even faster than the rapid increase in US utility patents. Private firms, universities, and the federal government all increased patenting in agricultural biotechnology. Universities have increased patenting in agricultural biotechnology particularly rapidly, and they now hold a greater proportion of agricultural biotechnology patents than they do of patents in general. Private firms tend to dominate patenting in plant technologies and molecular level agricultural biotechnology. Differences in patterns of patent production suggest not only differences in agricultural biotechnology research investment but also differences in motivations for patenting.

Key words: agricultural biotechnology, government, patents, patent portfolios, private firms, technology classification, universities.

Introduction

Over the past two or more decades, the structure of agricultural input industries has changed very rapidly. Private-sector investment in agricultural and food research and development (R&D) has grown dramatically, while public-sector investment has remained relatively constant. Private-sector plant breeding has been the fastest growing segment of the private research portfolio. Mergers, acquisitions, strategic alliances, and some divestiture in recent years have characterized the sector (Shoemaker et al., 2001). The use of intellectual property (IP), in the form of plant variety protection certificates and utility patents, has also expanded very rapidly over roughly the same time period. More than any other component of agricultural R&D, agricultural biotechnology exemplifies these trends.

In the literature on R&D, patents have often been used as a measure of inventive activity, because patent data are a relatively easy measure to acquire (see also Brennan, Pray, Naseem, & Oehmke, this issue). This article reports preliminary and descriptive data from the Agricultural Biotechnology Intellectual Property (ABIP) database (United States Department of Agriculture Economic Research Service [USDA ERS], 2004), in which agricultural biotechnology patents are grouped in several ways: by the type of institution (US or non-US firm, university, or government) to whom the patent is assigned, and by the technology type under which the patent is classified in the ABIP database.[1] These data are used to explore the question of what kind of institutions have been performing particular kinds of research in agricultural biotechnology. We will also consider whether patent data alone are sufficient to answer this question.

Use of patent data is not without its difficulties. Patents are sometimes used as a measure of output of R&D activities (Griliches, 1990) and sometimes as a measure of inputs into the production of goods and services (Schmookler, 1954). Even when the analysis is primarily restricted to private firms, it is difficult to relate patent data to economically relevant industry or product groupings. Many patents turn out to have very little economic value, while a few may prove to be extremely valuable (Griliches, 1990). Moreover, the "economic value" of a patent may be hard to define, as firms may use patents for a variety of reasons—for example, to block competitors' products, as bargaining chips in cross-licensing negotiations, or to prevent infringement suits—besides protecting returns to specific inventions (Cohen, Nelson, & Walsh, 2000). Public-sector institutions, such as universities or government agencies that patent, may do so for reasons differing from those motivating private firms (Henderson, Jaffe, and Trajtenberg, 1998; Jaffe & Lerner, 2001; Jensen & Thursby, 2001; Maredia et al., 1999). Finally, patent data are only one kind of indicator—other research input related data might include R&D expenditures, and other research

1. *Patents may be classified under more than one technology type, or they may not be classified at all, according to the current rule-based classification system used in the ABIP database. Multiple assignees for a given patent might also represent more than one type of institution, although this is a less frequent phenomenon. Also, assignees are not listed for some patents.*

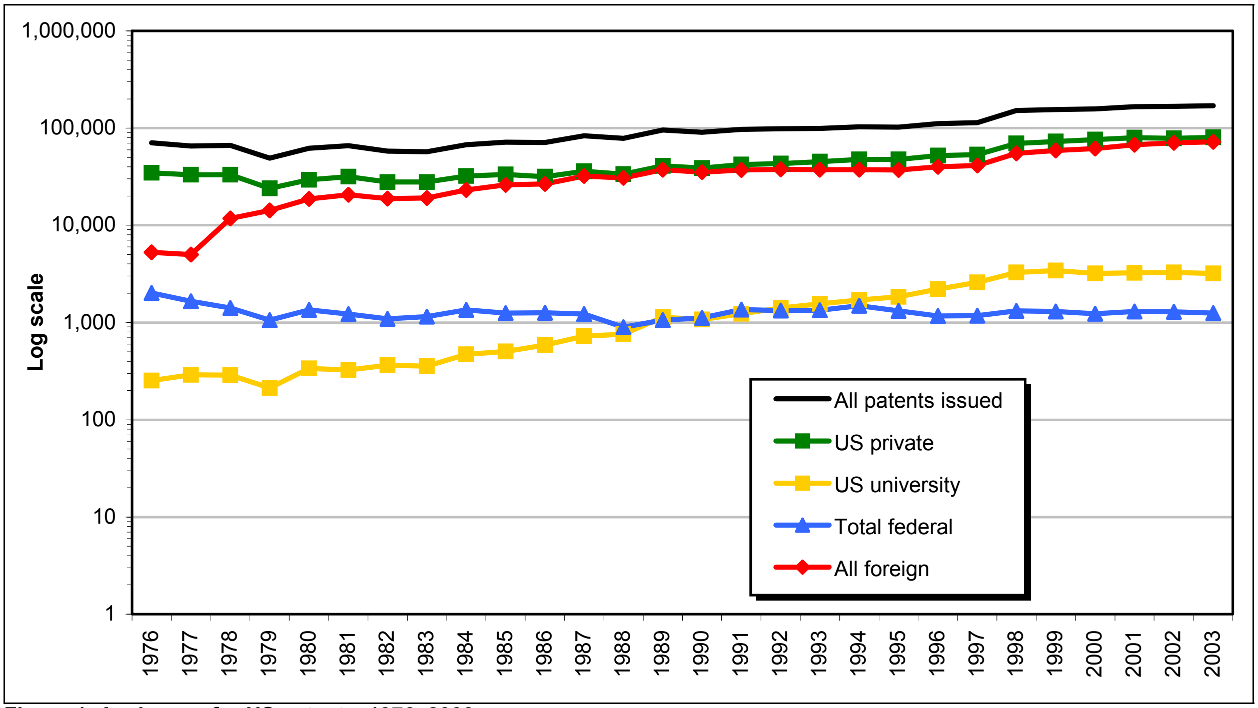

Figure 1. Assignees for US patents, 1976–2003.
Note. Data from the United States Patent and Trademark Office.

output data might include scientific publications. But patent data do tend to measure relatively near-market economic activity related to R&D. As long as these precautions are borne in mind, it is possible to obtain a partial picture of R&D in agricultural biotechnology from patent data. Our descriptive analysis demonstrates that patenting behavior in agricultural biotechnology differs across entity type and across time just as it does in the larger economy.

The Context: The Rapid Growth in Patent Numbers

In this paper we are particularly concerned with both differences and similarities in agricultural biotechnology patenting by different kinds of institutions—firms, universities, and governments—as well as by institutions based both inside and outside of the United States. At this point, therefore, it is useful to see overall trends in US utility patents by these different entity types. Figure 1 shows patenting by different assignee types for US firms, US universities, and the federal government from 1976 through 2003, as well as patenting by all non-US assignees.[2] It is clear that private firms, both US and non-US, dominate US utility patenting. Although the rate of growth in patents issued to non-US institutions has fluctuated, sometimes growing more quickly than the rate of growth in patents issued to US firms, sometimes more slowly, in recent years both US and non-US firms appear to have increased patenting at roughly the same rate. Currently, private firms are assigned 85–90% of all utility patents issued in a year, with US firms assigned somewhat more patents in each year than non-US firms.

US universities and other nonprofit institutions, as well as the US federal government, are issued a much lower fraction of total patents than private firms. All told, in most years from 1976 through 2003, US public and nonprofit institutions were issued only about 5–6% of all US utility patents. Nonetheless, the differences in overall patenting patterns between universities and federal research institutions are striking. Before leveling off around 1998, utility patenting by US universities grew much faster than patenting by any other type of institution. On the other hand, despite some apparent increases in federal patenting over some subperiods (Jaffe &

2. *It is relatively difficult to separate out universities and governments from other non-US assignees in the USPTO database. As is the case for US assignees, however, the vast majority of the non-US assignees are also private firms. This can be confirmed by viewing various reports on the USPTO web site (http://www.uspto.gov/web/offices/ac/ido/oeip/taf/).*

Lerner, 2001), federal patenting was essentially constant over the entire period from 1976 through 2003.

A number of factors could explain the unprecedented increase in applications for US patents and US patents granted in the period in question. Hall (2004) tested for a structural break in US patent applications and found it occurred between 1983 and 1984. Although there is a lag between applications and grants, it is clear that patents granted, too, began to increase at a more rapid rate about this time. As a point of comparison, from 1984 through 2003, US patents granted grew at an average rate of 5% per year, while US real GDP grew at an average annual rate of 3%.[3] Hall attributed much of the impetus for this structural change in patenting to behavior of US firms, although non-US firms also played a role. Hall also argued that although US firms increased patenting in all classes, the initial structural break was largely accounted for by firms in electrical and computing technology. In addition, other related technological areas, such as software and information technology, witnessed a rapid increase of innovation and new firm creation over much the same period as the increase in patents. One additional technology—biotechnology—has also been noted for the formation of new firms and rapid innovation rates over this period (Kortum & Lerner, 1999).[4]

This suggests one of four hypotheses tested by Kortum and Lerner: the "technological opportunity" or "fertile technology" hypothesis, which states that technologically dynamic fields like biotechnology and software drove the increase in patenting. They rejected this hypothesis, however. The number of biotechnology and software patents in their data set rose significantly from the late 1970s to 1991, as did the fraction of total patents represented by patenting in those two areas. Nonetheless, total patenting rose by almost 70% from 1983 to 1991; when biotech and software patents were excluded, total patenting still increased by 65%. Kortum and Lerner also rejected the "friendly court" and "regulatory capture" hypotheses. Almost by process of elimination, they concluded that the reason for the increase in patenting was an increase in the productivity of R&D in the US economy, at least in the areas of innovation that lead to patents. Kortum and Lerner developed a model in which an unexpected permanent increase in R&D productivity leads to a transitory increase in R&D and a transitory increase in patents. One difficulty with this explanation is, however, that R&D increased much sooner than did patenting (Jaffe, 2000). One possible alternative explanation that might help to explain the surge of patenting is the argument of Cohen et al. (2000) that firms use patenting for other reasons than simply to protect the returns to specific inventions.

Henderson et al. (1998) found that, in contrast with the total patent series, university patenting accelerated much earlier, beginning in the early 1970s (see also Figure 1). The increase in patenting by US universities could be attributed both to a greater propensity to patent per research dollar and the spread of patenting to many more universities. By far the largest increase in university patenting occurred in biomedical fields, which accounted for over a third of the university total by the late 1980s, but as was the case for general patenting, university patenting increased in many areas. Using citation-based measures of patent importance and generality, Henderson et al. (1998) found that university patents were of higher quality than a random sample of all patents until the early 1980s, but not significantly different in later periods.[5] Increasing propensity to patent at the same time that patent importance and generality were declining may be related to the likelihood that universities patent and/or license inventions at a very early proof-of-concept or prototype stage (Jensen & Thursby, 2001). The Bayh-Dole Act of 1980, allowing universities to obtain patent rights for federally funded research, was one of the causal factors behind the rapid increase in university patenting, but especially considering the fact that university patenting began to increase rapidly before the passage of the Act, it cannot have been the only factor. Other causal factors might include increases in university research funding, an increased attention to applied research, the growth of university technology transfer offices, and other changes in national intellectual property institutions, for example the expansion in patentable subject matter into areas such as genetically transformed organisms (Henderson et al., 1998; Jaffe, 2000; Mowery, Nelson, Sampat, & Ziedonis, 2001).

Jaffe and Lerner's study (2001) of patenting by 23 federally funded research and development centers

3. *These growth rates were calculated from publicly available data provided by the US Patent and Trademark Office and the Bureau of Economic Analysis, both part of the Department of Commerce.*

4. *This includes all biotechnology, not just agricultural biotechnology.*

5. *In contrast to the findings of Henderson et al. (1998), Mowery and Ziedonis (2002) found no apparent decline in patent importance or generality after 1980 for two of the leading academic patenters, the University of California and Stanford University.*

owned by the US Department of Energy showed some increase in the number of patents granted to these laboratories roughly throughout the 1980s. However, their data show a peak for patenting from these 23 laboratories in 1993, and the data for all patents whose assignee is some branch of the federal government show no discernible trend (Figure 1). Jaffe and Lerner also found, for the 23 laboratories in their sample, an increase in patenting intensity per research dollar up to 1994, with a slight decline thereafter. Unlike the case for universities, they found no decline in patent quality over the period they covered, 1978 through 1996. As with universities, the creation or expansion of technology transfer offices within federal labs have played a role in expanding transfer of federal technology through patenting (Day Rubenstein, 2003; Jaffe & Lerner, 2001).

Defining Agricultural Biotechnology in the ABIP Database

The ABIP database was constructed to allow both broad and narrow definitions of agricultural and food biotechnology. Most generally, agricultural biotechnology may be understood as the use of organisms or parts of an organism to make or improve products or processes in agriculture. The domestication of plant species and selection of desired characteristics within agricultural species would qualify under this definition. More narrowly, what biotechnology represents today is new knowledge about the natural processes of DNA replication, breakage, ligation, and repair that has made possible a deeper understanding of the mechanics of cell biology and the hereditary process itself (McCouch, 2001). Although in agriculture the term *biotechnology* has been most closely associated with genetic manipulation at the DNA level, or genetic engineering, it may refer to a variety of techniques or products. These may include, for example, use of molecular markers in genetic improvement or more general use of genomic information. Similarly, the use of enzymes for fermentation in brewing or cheesemaking would be early examples of a broadly defined food biotechnology. Genetically engineering yeast to modify or improve a baking process would be an example of a narrower or more recent definition of food biotechnology.

The ABIP database includes patents in broadly defined agricultural and food biotechnology issued from 1976 through 2000. The ERS was granted access to the databases used by Graff and colleagues and by Foltz and colleagues, so there is a large overlap in coverage between patents in these databases and the ABIP data set (see Barham, Foltz, & Kim, 2002; Foltz, Kim, & Barham, 2003; Graff, Cullen, Bradford, Zilberman, & Bennett, 2003; Graff, Rausser, & Small, 2002). For this paper, however, we also used the classification system in the ABIP data set to develop a smaller data base of "modern" agricultural biotechnology patents. These patents consisted of patents classified into the categories of genetic transformation, DNA-scale biological processes, or genomics, and applied either to plants or animals, not including microorganisms. The ABIP database was compiled independently from another database used by Buccola and Xia (2004) but covered similar time periods. The absolute numbers of modern agricultural biotechnology patents studied by Buccola and Xia (1,746 patents) and in the ABIP database (2,058 patents)[6] were quite similar. We also compared some of the patterns in patenting of modern agricultural biotechnology, by different types of institution over time, with Figure 1 in Buccola and Xia and also found that the patterns were similar. Therefore, there is evidence of considerable overlap between the modern agricultural biotechnology patents in the ABIP database and the database used by Buccola and Xia.

Agricultural Biotechnology Patenting Over Time and by Sector

The rapid rate of increase in agricultural biotechnology patents relative to the overall rate of increase in US utility patenting is noted elsewhere in this volume (e.g., Brennan et al.). Here, we can also compare the rate of increase in modern agricultural biotechnology patents with the rates of increase in all agricultural biotechnology patents and all patents (Figure 2). As fast as patenting grew in broadly defined agricultural biotechnology, it grew even faster in modern agricultural biotechnology. In the early years of our sample, there was almost no patenting that could be considered modern agricultural biotechnology. From 1980 to 1984, modern agricultural biotechnology patents averaged about 3% of all agricultural biotechnology patents. By the 1996–2000 period, they averaged roughly 22% of all patents in agricultural biotechnology. Nonetheless, the rapid expansion of modern agricultural biotechnology patenting does not account for all the growth in total agricultural biotechnology patenting. Even when modern agricul-

6. *Of the 2,058 modern agricultural biotechnology patents in the ABIP database, 1,904 patents had listed assignees. These 1,904 patents will be used in much of the rest of this paper to represent modern agricultural biotechnology.*

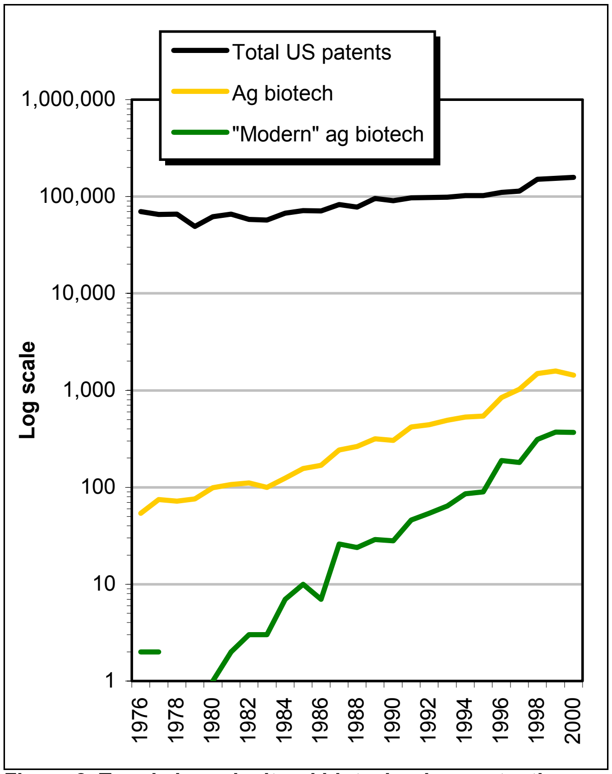

Figure 2. Trends in agricultural biotechnology patenting.
Note. Data from ABIP database (USDA ERS, 2004) and the United States Patent and Trademark Office. Blanks in series indicate a zero count, not missing data. These are not recorded because of the logarithmic scale.

tural biotechnology patents are extracted from the rest of the agricultural biotechnology sample, agricultural biotechnology patents still grew much more quickly than did total patents.

Figure 3 refines the data on agricultural biotechnology patenting by sector over time as presented by Brennan et al. (in this issue). As they showed, the entities with the largest numbers of agricultural biotechnology patents have been US firms, non-US firms, and US universities. Comparing Figure 3 with Figure 1 indicates that US universities were assigned a far higher percentage of the patents in agricultural biotechnology than they were in all technological areas. Although in the final years of the series agricultural biotechnology patenting by US universities fell off somewhat, over the entire time period US universities' rate of patenting in agricultural biotechnology increased even more quickly than did patenting by private firms. Agricultural biotechnology patenting by the US government, non-US governments, and non-US universities was at much lower levels than patenting by the other types of institutions. It is interesting to note, however, that non-US universities, like their US counterparts, increased their agricultural biotechnology patenting at the US Patent and Trademark Office (USPTO) at a somewhat faster rate than either private firms or governments.

Patenting in modern agricultural biotechnology by different kinds of institutions over time demonstrates the same general patterns as patenting in all agricultural biotechnology, but with some notable modifications (Figure 4). Modern agricultural biotechnology patenting by firms and US universities has taken place at much higher levels than patenting by the US government and non-US governments and universities. US firms began to patent sooner than did either non-US firms or US universities, and they have maintained this numerical advantage over time. Among institutional types with relatively few patents in modern agricultural biotechnology, non-US universities expanded their patenting quite rapidly over the middle to late 1990s. The US government has been assigned relatively few patents in this technological area.

Patent Portfolios by Institutional Type

The six kinds of institutions covered in the ABIP database—private firms, universities, and governments, both US and non-US—may be patenting in different technological areas of agricultural biotechnology in addition to any broad trends in totals over time. In this section we explore a few of those differences.

Approximately 16% of all patents in the database are not classified into any technological categories at present. For US firms it is slightly easier to classify patents, and only 14% remain unclassified into technological categories. Some patents deliberately may be classified into more than one technological category. For example, a patented cultivar that included a gene insertion might be classified under both *plant technologies* and *genetic transformation*. For these two reasons—incomplete coverage and overlap—complete classification of patents into all technological categories cannot be regarded as a frequency distribution whose components sum to one.

Figure 5 shows patent portfolios for all six kinds of institution across several notable technological categories for the entire period 1976 through 2000 (small patent numbers in some categories prevent further disaggregation over time). It should be borne in mind that these are percentages of all agricultural biotechnology patents issued to each type of institution between 1976 and 2000, and not absolute numbers of patents. Thus, they measure the relative propensity of each entity type

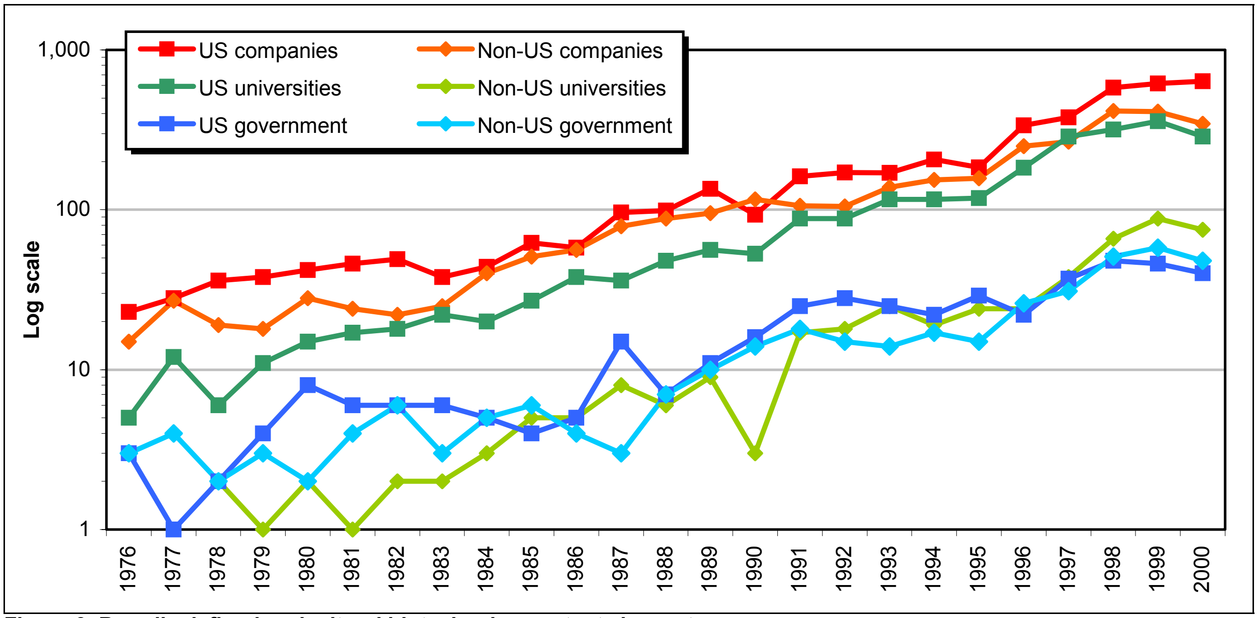

Figure 3. Broadly defined agricultural biotechnology patents by sector.
Note. Data from ABIP database (USDA ERS, 2004).

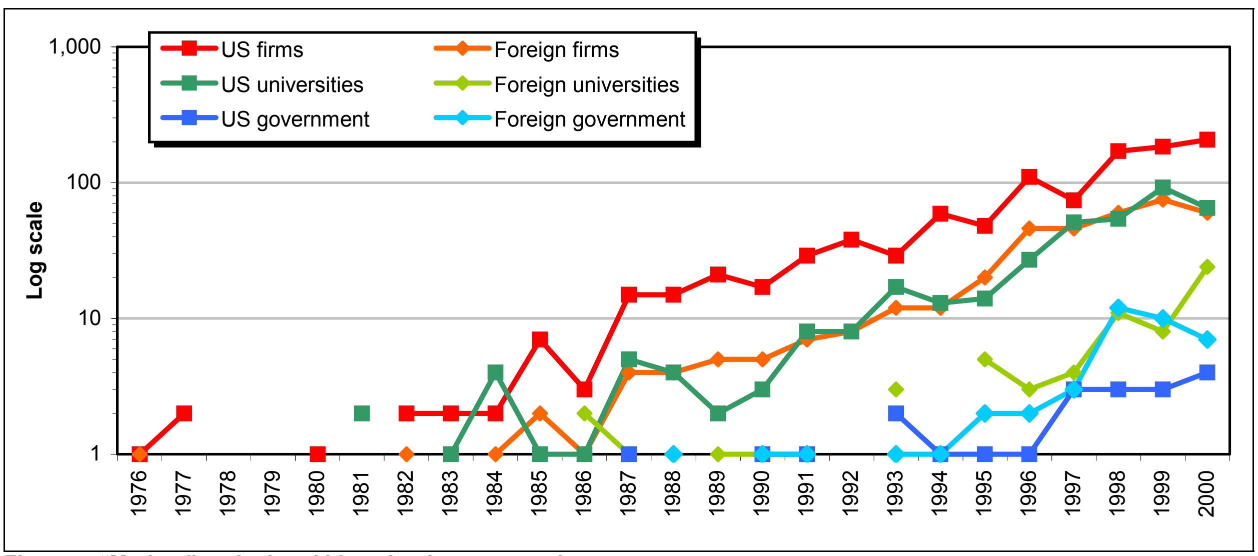

Figure 4. "Modern" agricultural biotechnology patents by sector.
Note. Data from ABIP database (USDA ERS, 2004). Blanks in series indicate a zero count, not missing data. These are not recorded because of the logarithmic scale.

to patent in a given technological area and not the absolute importance of a given institution to total patenting in any particular subtechnology.

From 1976 through 2000, US firms were most likely to patent in modern agricultural biotechnology, followed by universities, both US and non-US (first column, Figure 5). On the other hand, the US government was least likely to patent in this area. In the case of general plant technology (including both modern plant biotechnology and other plant-related technologies), all private firms, both US and non-US, were more likely to patent than were universities or governments (second column, Figure 5). The third column of Figure 5 looks at the intersection of these two technology types, namely the propensity to patent in modern plant biotechnology—the technological category most associated with agricul-

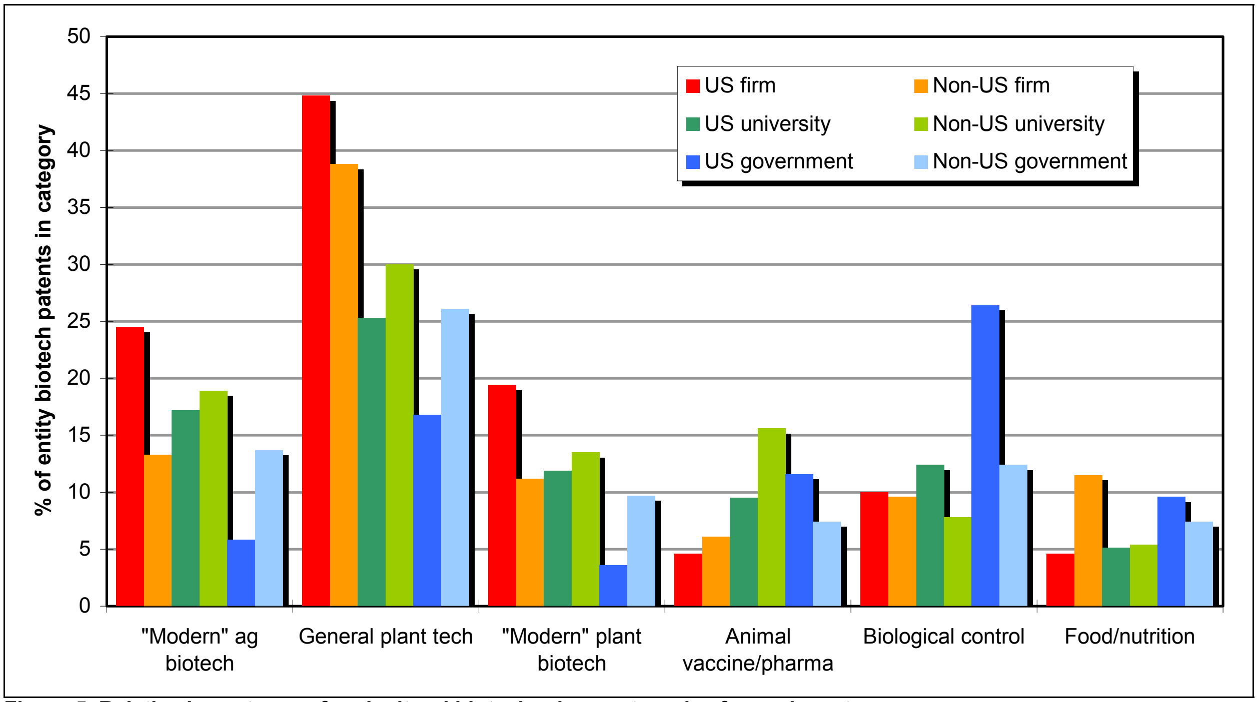

Figure 5. Relative importance of agricultural biotechnology categories for each sector.
Note. Data from ABIP database (USDA ERS, 2004).

tural biotechnology in the popular conception. US firms were clearly more likely to patent in modern plant biotechnology than the other entity types, and the US government less likely to do so than the others.

Patenting in a specific type of plant biotechnology—plant cultivars—is also of interest. US patents for cultivars are now issued whether or not they result from the use of some molecular technique such as gene insertion. Private firms almost completely dominate cultivar patenting, and, in fact, US private firms patent far more cultivars than do non-US firms (Figure 6). Furthermore, two firms—Pioneer/DuPont, and Monsanto, especially its subsidiaries acquired in recent years—dominate cultivar patenting. Two crops—corn and soybeans—also account for most of the US utility patents on plant cultivars.

Several other notable technological areas are depicted in Figure 5. Non-US universities and the US federal government, followed by US universities, are relatively more likely to patent animal vaccines and veterinary pharmaceuticals (fourth column). The federal government clearly devotes a substantial proportion (a little over one quarter) of its patenting in agricultural biotechnology to patents that concern biological control of pests and diseases for plants and animals (fifth column). No other type of institution devotes more than one eighth of their patent portfolio to biological control. Finally, relatively few of the patents in the ABIP database relate to food or nutrition. However, non-US private firms and the US government patent relatively more in this area than do other institutions.

Other Studies of Agricultural Biotechnology Patents

Several previous studies have addressed some specific issues concerning patenting in agricultural biotechnology, using different data sets and motivated by a variety of concerns. Buccola and Xia (2004) used a more restrictive definition of agricultural biotechnology, similar to what we have defined as modern agricultural biotechnology. They focused particularly on agricultural biotechnology by private firms. They assessed an apparent decline in patent quality using citation-based measures and proposed two hypotheses to explain this decline. First, a “technological hypothesis” proposed that agricultural biotech patents are moving downstream. Second, a “strategic hypothesis” suggested that firms are patenting more to maximize the value of their patent portfolios. They determined that the evidence may support both the technological and strategic hypotheses.

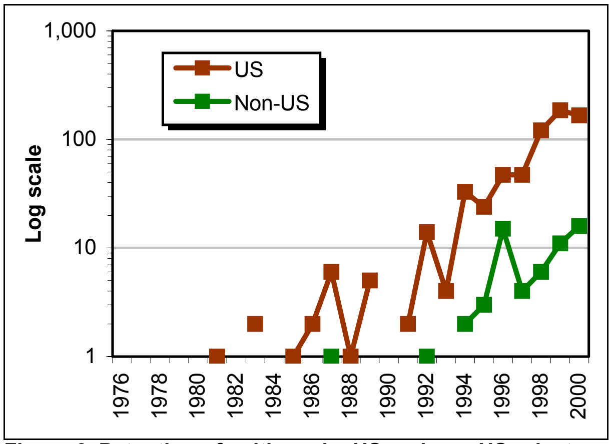

Figure 6. Patenting of cultivars by US and non-US private firms.

Note. Data from ABIP database (USDA ERS, 2004). Blanks in series indicate a zero count, not missing data. These are not recorded because of the logarithmic scale.

Graff et al. (2002, 2003) also focused on patenting by firms. Their definition of agricultural biotechnology was broader, however, and it included such areas as crop germplasm that may not have been developed using the techniques of molecular biology. They defined three different kinds of technology—germplasm, transformation platforms, and traits—and found that firm mergers tended to combine different types of technology. Schimmelpfennig and King (2004) used the same broader ABIP data set that we are using in this paper, also to focus on firm behavior. They argued that firms have used mergers to get around IP licensing holdups. They also noted that firm behavior might differ based on the type of firm.[7] They also found that higher quality patents were less likely to change hands through mergers or acquisitions.

Barham et al. (2002) and Foltz et al. (2003) also maintained a relatively broad definition of agricultural biotechnology, but they focused on patenting by universities. They examined factors explaining the level of university patenting in agricultural biotechnology and found that previous patenting experience, overall university propensity to patent, land-grant status, and level of funding for biological sciences all increased the numbers of agricultural biotechnology patents assigned to particular universities. University reliance on industry financing did not, however, increase patent production in their study. They found limited evidence of local economic spillovers from university agricultural biotechnology patenting.

Xia and Buccola (2005) identified scientific publications cited by agricultural biotechnology patents and traced these citations to the universities that performed the research. They found that universities are a principal source for the science that led to agricultural biotechnology, that a university's life-science research budget affects its biotechnology-relevant science, and that returns to research budget scale are decreasing in the short run but increasing in the long run.

Discussion and Conclusions

The pattern of agricultural biotechnology patenting clearly differs across sectors. As noted, US private firms, non-US private firms, and US universities dominate patenting in both general agricultural biotechnology and "modern" agricultural biotechnology, which involves greater use of molecular-level information. Furthermore, US firms take the lead over all other types of institutions not only in total numbers of agricultural biotechnology patents but also in portfolio concentration in modern agricultural biotechnology, modern plant biotech, plant cultivars, and general plant technology. Non-US firms, in general, have patent portfolios somewhat similar to US firms, but their portfolios are somewhat more diffuse and harder to characterize. Non-US firms also patent relatively more in food and nutrition related areas than all other types of institutions.

Universities—at first US universities, but in more recent years non-US universities as well—have increased their patenting in both general and modern agricultural biotechnology more rapidly than any other type of institution. The rapid growth in agricultural biotechnology patenting by US universities has occurred in tandem with the accelerated rate of patenting by these universities in all technological areas. In fact, US universities' patenting in agricultural biotechnology, as a percentage of all agricultural biotechnology patents, is much higher than US universities' percentage of all US utility patents. Clearly, these universities are playing a major role in agricultural biotechnology, at least as indicated by patenting behavior. However, it is harder to characterize their agricultural biotechnology patent portfolios. Across the technologies presented in Figure 5, US universities' portfolios appear similar to US firms' portfolios in terms of distribution, but the frequencies of university patenting in each area are lower, suggesting that university patenting is more diffuse than patenting

7. *Some of the types of firm defined by Schimmelpfennig and King (2004) were multinationals, chemical firms, seed firms, and agbiotech firms.*

by firms. In both vaccines and veterinary pharmaceuticals, as well as in another technological area not reported in Figure 5—general animal technologies—both US and non-US universities tend to patent relatively more frequently than do private firms.

The US federal government has expanded its agricultural biotechnology patenting at a somewhat slower rate than either private firms or universities. Furthermore, its pattern of patenting is quite distinctive. It is far less concentrated in modern agricultural biotechnology, modern plant biotechnology, and general plant technology than the patenting by all other institutional types. The primary US federal agricultural research institution—the Agricultural Research Service of the US Department of Agriculture—has, of course, done a great deal of research in plant science over many years. Patents therefore do not particularly represent US federal research in this area. On the other hand, US federal patenting is somewhat more concentrated in food and nutrition, vaccines and veterinary pharmaceuticals, and particularly biological control, than is the patenting by other entity types.

Patent statistics may suggest other questions about agricultural biotechnology R&D, although they may not provide complete answers to these questions. The differences in patterns of patent production suggest that not only differences in agricultural biotechnology research investment but also differences in motivations for patenting might explain patenting behavior by firms, universities, and governments. Most studies of agricultural biotechnology patenting to date have addressed motivations for patenting by different types of institutions only obliquely, if at all, but the general literature does suggest some factors. Firms patent to protect their inventions, to develop strategic patent portfolios, and (perhaps in some cases) to generate licensing revenue (Cohen et al., 2000; Jaffe, 2000). Universities may patent as a means to transfer technology to the private sector for further development, to attempt to generate licensing revenue, or perhaps to contribute to regional economic development through spinoffs and science parks. These motivations for patenting by universities, in particular, are often merely stated in the literature rather than analyzed in any detail. The US federal government, on the other hand, patents particularly as a means of technology transfer (Day Rubenstein, 2003; Jaffe & Lerner, 2001).

Among the other questions patent data might address, knowledge about the patenting of research tools might help to understand the direction of knowledge flows as well as to assess the potential for research hold-ups. We performed an initial classification of the ABIP database into potential research tools. As with modern biotechnology, US and non-US firms, as well as US universities and other nonprofits, did far more patenting in this area than did other institutions. A deeper analysis of which patents are actually the key patents in a given technological area might prove extremely useful. Such a strategy would be particularly relevant in the case of research tools.

Several other approaches to analysis would also expand our understanding of who is doing what in agricultural biotechnology. On the research input side, data on investment in agricultural biotechnology would be valuable. A breakdown of this investment by technological area and other indicators of research objective would add even more. Unfortunately, detailed data on R&D investment in agricultural biotechnology are often either unavailable or nonexistent. On the research output side, research publications are an alternative measure, although not strictly comparable to patents, because they might represent somewhat more basic research than the research that results in patent applications. Determining university priorities in agricultural biotechnology, for example, requires analysis of multiple indicators such as publications (Xia & Buccola, 2005). Modern agricultural biotechnology in many ways represents a spillover from basic molecular biology into agriculture by way of biomedical science. Patent statistics alone will not tell that story.

What the patent data do confirm, however, is the current importance of private firms, particularly US private firms, in commercializing agricultural biotechnology, in particular plant-related technologies and modern agricultural biotechnology that relies more on the application of molecular biology. This is a completely expected result. The data also confirm that the US government only tends to patent in specific agricultural biotechnology research areas rather than broadly across all agricultural areas in which it performs research. This government patenting appears to be mainly in support of technology transfer. The complex role of US universities in patenting remains less clear. Obviously they are important players in agricultural biotechnology in terms of patent counts, but with some exceptions, their patent portfolio mimics the portfolio held by the private sector. Universities, however, do not appear to patent very near-market technologies such as plant cultivars.

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