Trends in University Ag-Biotech Patent Production*

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Abstract:
This work exploits information on U.S. patents to identify trends in university ag-biotech patenting and citation performance. It sets forth some key issues concerning patterns of university ag-biotech patenting and then provides an empirical analysis on the evolving trends. Land Grant Universities account for most U.S. ag-biotech patents. The data show a path dependent innovation pattern, in which there also seems to be a culture of patenting that develops at certain universities. Evidence shows that ag-biotech patents are more cited than the average university patent. Inequalities across Land Grant Universities are also evident in the production of ag-biotech patents, although perhaps not to a much greater degree than underlying inequalities in funding and research qualities. The paper closes by considering how the evidence offered might be used to advance the public discussion regarding trends in agricultural biotechnology research in the U.S.

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Trends in U.S. University Ag-Biotech Patent Production

Agricultural research has historically exhibited high rates of social return (Alston and Pardey), thereby bolstering the case for public support of research, especially at land-grant universities. Recently, however, scholars and blue-ribbon review panels have expressed increasing concern that the Bayh-Dole Act, which allowed universities to sell exclusive licenses to their inventions, and agricultural biotechnology (ag-biotech) are part of a privatization of publicly sponsored agricultural research, which may reduce the social returns. Examples of these concerns with the social welfare implications of new patterns of intellectual property rights management and conduct are explicated in many publications including a report by the National Association of State Universities and Land-Grant Colleges, an entire issue of *AgBioForum*, and books by Fuglie and Schimmelpfennig and by Wolf and Zilberman.

At the heart of the controversy is the fact that agricultural research advances that universities used to publicly disseminate without charge may now be guarded as valuable secrets, patented to create intellectual property rights, and licensed or commercialized in concert with private firms under potentially monopolistic conditions (Weatherspon, Oehmke, and Raper). While it is entirely appropriate that the normative (welfare) implications of these changes have been the predominant focus of the discussion, systematic evidence is still missing about the actual patterns of university patenting, citation, licensing, and other outcomes associated with ag-biotech research. That is, there is a need for data that could help sharpen the focus of ongoing research and policy work in this arena around what is actually happening in the realm of ag-biotech research in U.S. universities.

In particular, it would help to know the answers to issues such as: (1) What are the temporal trends in university patents, citations, and revenues from ag-biotech research? In terms of university research, are we in the midst of an ag-biotech revolution? (2) Who are the leading universities in producing ag-biotech patents, securing citations, and earning revenues? (3) Is university leadership in this arena persistent over time or subject to major changes? (4) What are the main factors that explain university ag-biotech patent production, citations, and revenues? (5) Is there evidence of local business or research spillovers from ag-biotech patents and citations as there has been in the pharmaceutical side of biotechnology research? (6) Overall, is ag-biotech research likely to deepen or reduce historical patterns of inequality in resources and capabilities within land-grant institutions?

In this paper, we draw on U.S. patent and citation data to examine trends over the past twenty-five years in ag-biotech. The next section sets forth in more detail some key issues concerning patterns of university ag-biotech patenting and citations. Section III provides a careful description of the data used for the analysis. The empirical analysis in Section IV offers evidence on the evolving trends of university ag-biotech patenting and citations to help answer the key issues. The paper closes by considering how the evidence offered might be used to advance the public discussion regarding the changes occurring in ag-biotech research in the U.S.

II. Key Issues

In recent years, a number of key issues associated with university production of ag-biotech patents have been raised. The time is ripe for an appraisal of the data in this arena to identify what we can say already and what needs further investigation.

Ag-Biotech Patenting Trends

Which universities are taking the lead in ag-biotech patenting and how many patents are they producing? While public debate on the merits of ag-biotech patenting has intensified, actual data on the number of ag-biotech patents produced and who is producing them have been non-existent.[1] Aside from knowing who has produced how many patents one might also ask whether Land Grant Universities are the leaders in ag-biotech patenting or whether due to complementarities with non-agricultural biotech research other types of universities (e.g., Harvard and MIT) are major players.

Persistence

Does initial success in ag-biotech patenting produce the ability to do more patenting? Is there persistence in university patenting (and citations)? If this were the case, universities who did not enter the ag-biotech patent game early would find it difficult to catch-up. In the literature on industry innovation, this persistence in innovation is often described as "deepening". The opposite dynamic would be a process of widening in which over time more universities can participate in the production of ag-biotech patenting. Patterns of widening are common when information flows easily across institutions and there are few barriers to entry, while patterns of deepening are common when there are constricted information flows and increasing returns in innovation production.

A related concern is whether because of the incentive to patent universities and their scientists are acting more like competitive companies and withholding information from erstwhile competitors rather than like the knowledge generators and sharers they have historically been. Of course many other things besides the degree of information sharing across universities will determine persistence, including heavy investment costs in laboratories, dynamic learning in the tech transfer process, and the like. Thus, evidence of persistence, while it cannot be equated directly with problems of information flows, provides some suggestion as to whether it could be a problem.

Determinants of patenting success

What are the key determinants of ag-biotech patenting performance across universities? How important is the land-grant effect (a history of agriculture related research)? Does industry financing matter? Are there identifiable synergies with biology departments? How important are technology transfer offices? We augment the patent data used here with results from an econometric analysis developed in Foltz, Kim, and Barham to provide some initial answers to these questions.

University Research Spillovers

Are there significant economic spillovers to university ag-biotech patenting? While traditional agricultural research is well known to create significant spillovers both locally and nationally, the intellectual property rights associated with ag-biotech patenting create a different dynamic. At issue is who uses and who benefits from patented ag-biotech innovations. Citation data offers evidence on the relative levels of usage of university patents in other patents from the same university, U.S. companies, other universities, and foreign companies. Work by Jaffe, Trajtenberg, and Fogarty has also shown a significant correlation between patent citations and the economic and technological importance of patents.

Local Spillovers

Does university ag-biotech patenting produce spillovers that are locally appropriated within a state's economy or is the research a national public good? Studies of pharmaceutical biotech (e.g. Audretsch and Stephan; Zucker, Darby and Brewer) find evidence that university research has generated industry clusters concentrated around major research universities due to knowledge spillovers into local companies as well as the creation of start-up companies based on university technology. Recent work on ag-biotech (e.g. Zilberman, Yarkin, and Heiman; Foltz, Barham and Kim) has tended to presume that ag-biotech research will produce a strong pattern of local spillovers from universities.

Many states have started to invest heavily in promoting ag-biotech research capacity in order to take advantage of these perceived agglomeration economies or local spillovers. In the case of ag-biotech, the technology may have national or international rather than local adoption patterns and be produced by dominant global firms, thus undercutting in two ways the logic of public investment in university research for the purpose of generating local economic spillovers. The citations data used here offer preliminary evidence on the geography of economic spillovers from ag-biotech patenting by addressing whether university ag-biotech patents foster more ag-biotech research by in-state companies or out-of-state companies.

Inequality

Does ag-biotech patenting generate inequalities among universities? One of the arguments for allowing universities to patent their innovations is the incentive provided by the potential for revenues from those patents. Some observers (Ohmke et al.) have worried that ag-biotech patenting may become a lucrative revenue stream only available to the larger, more research oriented Land Grant Universities leaving smaller universities at a disadvantage in this and other arenas. The patent data are used to provide evidence on the levels of inequality of patent production, which is then compared with levels of inequalities in graduate student enrollments and agricultural research funding. Citation data are also used to provide further evidence about the extent of inequality in the quality of ag-biotech research.[2]

III. Data on Ag-Biotech Patenting:

The patent data used here come from a search of the U.S. Patent office database for university owned utility patents that were both agricultural and biotechnological.[3] We considered all patents in U.S. classes 435, 800, 935 as biotech and then searched within them for those that were agricultural. The definition of agriculture we used required that the technology: 1) uses extensively a product produced on a farm; or 2) modifies or improves a product produced on a farm; or 3) modifies, improves, or produces a food, wood, or aquaculture product. Note that this definition excludes a number of technologies including: (i) any animals or plants produced entirely for research purposes (e.g., mice, rats, monkeys); (ii) any animal primarily designed as a pet: e.g. dogs and cats; (iii) any product that merely uses animal or plant cells in minor quantities for a non-agricultural product; or (iv) any vaccine or vaccine technique or disease diagnostic technique that is intended primarily for use in humans, or on human diseases, or on diseases not currently treated in animals. Note that the database does include utility patents on plants intended only for ornamentation so long as they fit the definition of being biotechnology.

The search yielded 795 ag-biotech patents in total owned by 107 different universities as of the summer of 2000. It is worth noting that patents represent only a small component of the research output of universities. Thus, the ag-biotech patent numbers are not meant to represent overall university ag-biotech research output. They do, however, provide an accurate measure of the intellectual property rights owned by a university in ag-biotech and are likely in most cases to be strongly correlated with overall research production in this arena.

The patent data were then used to search for citations. Studies of patent citations have shown that they do provide a reasonable proxy for both quality of a patent and knowledge spillovers from it, because each time a new patent uses a piece of research from another patent it is obligated to cite the previous patent (Jaffe, Trajtenberg and Henderson; and Henderson, Jaffe, and Trajtenberg). Thus, at a minimum, a patent citation suggests a knowledge spillover (either direct or indirect) and often suggests that some royalties or licensing revenues are being or will later be paid.

For each identified university patent, we searched the U.S. Patent Office database for citations of those patents. Each of the citing patents was then retrieved to check whether it was (1) by the same authors, (2) owned by a university or business or foreign economic agent[4], and, (3) whether either the authors or the assignee (university or company) of the citing patent was in the same state as the original patent owner. We can thus distinguish between different types of in-state citations: those made by the same researchers, those assigned to the same university with different authors, those assigned to a business in-state or business patents with in-state inventors, and those assigned to another university in-state. The last category has very few observations.

IV. Empirical Evidence

A) Key Trends in U.S. University Ag-Biotech Patent Production

Judging by the recent explosion of accepted patents among land-grant universities in the United States, the long-touted ag-biotech revolution is underway. As shown in Figure 1, the actual number of U.S. university-owned ag-biotech patents accelerated gradually from around 10 granted per year at the outset of the 1980s to around 25 per year in the late 1980s, early 1990s.[5] The breakout year was in 1996 for which 78 patents were granted, while 1997, 1998, and 1999 gave rise to 105, 124, and 174 accepted patents respectively. Thus, for the four latest years, the number of patents secured, 481, exceeds the cumulative total of 314 for the first 20 years of U.S. university's ag-biotech patenting.

B) Who are the leaders?

The first two columns of table 1 show that the top 20 universities, ranked by accepted ag-biotech patents during this time period, are, with the exception of the University of Pennsylvania (#17), all public land-grant institutions, with agricultural colleges.[6] As of the summer of 2000, the top five ag-biotech patent holding universities were, respectively, the University of Wisconsin with 53, Cornell with 52, Iowa State with 47, Michigan State with 44, and the University of California at Davis with 32. The next five universities, University of Florida, Purdue, University of Minnesota, Louisiana State, and North Carolina State have more than 20 ag-biotech patents, and the 11th-20th all have, as it turns out, between 11 and 19 ag-biotech patents. Overall, ag-biotech patent holdings among U.S. universities are moderately concentrated. The top five holders mentioned above have 29% of the total number of patents, the top 10 have 45%, and the top 20 have 63%. Ag-biotech patent holdings among U.S. universities are almost completely dominated by public land-grant institutions who hold 84% of the total issued in the past 25 years.

C) Persistence

Using 1996 as the "take-off" year, we divide the sample into a ranking for the whole period and one for the pre-take-off period up to 1995. Over time these ag-biotech patent production rankings show strong signs of persistence with a few notable changes. If one compares the top ranked ag-biotech patent holders during the 1976-1995 period with that of 1976-2000, shown in columns 1 and 3 of Table 1, one finds several indicators of the persistence among the leaders:

(1) 15 of the top 20 overall in 2000 were also in the top 20 in 1995.

(2) The top 2 (University of Wisconsin and Cornell) have remained the same over both time periods, as they went from 29 and 21 patents in 1995, to 53 and 52 respectively for the 1976-2000 time-period.

(3) The top five ranked universities in 1995 were all still among the top ten over the 1976-2000 period.

(4) All of the top-10 ranked universities in 1995 remained in the top 20 over the 1976-2000 period.

(5) The top five patent producers between 1996 and 2000 were all in the top 15 in 1995.

Among the notable changes in the top 20 rankings are:

(1) The emergence of Michigan State as the most productive university between 1996 and 2000. During this time they moved from #12 in 1995 to #4 overall, as they went from 7 to 44 patents.

(2) The jump of Texas A&M (#11), Rutgers (#13), University of Pennsylvania (#17), University of Kentucky (#18), and Penn State (#20) from zero patents into the top 20.

D) Determinants of Patenting Success:

The rather strong pattern of persistence in ag-biotech patent production over the two time periods shown in the previous section is particularly noteworthy given the dramatic growth of patents acquired by universities over the past few years. This leads us to consider what determines ag-biotech patenting in general and the persistence of production in particular. This sub-section summarizes the major determinants of successful patent production using results from a dynamic count model reported in Foltz, Kim, and Barham.[7]

First, not surprisingly, that work finds strong evidence of a Land Grant effect in ag-biotech patenting. This means that the long-standing emphasis of Land Grant institutions on agricultural research and the associated funding provided by federal and state sources is a major determinant of the number of ag-biotech patents produced by universities. That work also identified econometrically what was shown above in the persistence discussion, namely universities with initial success in obtaining ag-biotech patents tend to receive more patents in the future. Work on manufacturing firm patenting by Blundell, Griffiths, and Van Reenen shows a similar dynamic effect in patenting. This finding on dynamic effects for university patenting underscores the likely existence of important learning costs for catch-up for universities that are not yet active in ag-biotech research. The presence of university-specific effects characterized by the degree of investments in technology transfer infrastructure is also detected. However, these effects are more related to the quality of investments in tech transfer (e.g., the university-wide ratio of invention disclosures turned into patents) rather than the quantity of investment (e.g., the size of the work force in the technology transfer office).

The econometrics, however, do not reveal strong linkages between ag-biotech patent production and levels of industry funding. In other words, industry funding does not seem to play a significant role in influencing patent production in university ag-biotech research. Instead, levels of own institutional and state funding are the most highly correlated with ag-biotech patent production. No synergy effect of having a high quality biology department, as measured by the number of biological science graduate students, was detected. One way of explaining this result may be that a necessary condition for ag-biotech patent production is having departmental units focused on applying innovation to agricultural problems, such as plant pathology and animal science. This result is also consistent with the significant Land Grant effect mentioned earlier.

E) Citations – Quality, Spillovers and Local Spillovers

Quality

We use patent citation data to construct a measure capturing the importance of the invention conveyed by a patent. Notice that this approach requires an implicit view of technology as an evolutionary process, in which the significance of a particular invention can be evaluated by the degree of its impacts on future inventions. For example, a citation of Patent X by Patent Y means that X possesses a piece of knowledge upon which Y invented, thus indicating the significance of X in stimulating and facilitating the invention of Y.

Following Henderson et al. we define a citation-based importance measure by total citations received. As shown in Figure 2, across the years the number of total citations per patent (mean citations) varies approximately between 2 to 12. The higher citation numbers correspond to the middle and late 1980s and lower numbers to the later periods of our data. The recent drop-off probably represents a data artifact rather than an actual trend toward lower citation levels. The first citations of a patent typically appear at least 3 years after a patent has been granted, so that we would expect the recent ag-biotech patents to show, on average, fewer citations.

About 45 percent of the patents had received at least one citation by the summer of 2000, which is lower than the percentage (about 70-90 percent) reported in Jaffe et al. (1993) for their sample of all university patents. However, since more than half of the ag-biotech patents were granted in the late 1990s, a more appropriate comparison is with the pre-1996 data, of which 83% had at least one citation. The mean number of citations received per patent over all data periods is 2.75. Again truncating our sample at 1996, however, one finds that the mean number of citations reaches 7.13. This compares favorably to the levels, 6.12 for 1975 and 4.34 for 1980, found by Jaffe et al. (1993) for all university patents, suggesting that ag-biotech patents by this measure may be more important research innovations than the average university patent. Since most of these are still young patents, one can expect to see a great deal more citations of ag-biotech patents in the near future, although it is also safe to presume that citation rates on earlier patents may be greater.

Table 2 presents citations of ag-biotech patents broken down by university. Considering the first column, one notices that the top three patent producers, Wisconsin, Cornell, and Iowa State, are among the top five in producing citations. Ohio State and UC-Berkeley move up the rankings into the top five, although this may in part be due to the more advanced age of their patent portfolios. Two other surprising examples in the data of universities with smaller, but more highly cited patent, portfolios are Harvard and Ohio University with 4 and 5 ag-biotech patents respectively, but 139 and 142 citations of those patents. The data do not show that universities producing a lot of ag-biotech patents are also producing patents of higher levels of citations than lower producing universities. Estimates of the correlation of citations per patent and number of patents by a university were marginally negative (-0.07) for both the full and 1995 samples and not significantly different than zero for either one. This suggests no synergies between quantity and quality, as measured by citations, in ag-biotech patenting. Such an outcome would be consistent with the common notion that a patent is like a lottery ticket.

Spillovers

Next, we investigate who cites university ag-biotech patents. This may uncover some idea of the knowledge and economic spillover effects from university innovation represented by ag-biotech patents. One needs to understand that the data only examine the group of "spillovers accompanied by citations", even though some citations can occur without producing either knowledge or economic spillovers and some spillovers can occur without generating a citation.[8] As indicated in Table 2, more than half of the citations were made by businesses. Universities accounted for about a quarter of the citations, followed by foreign assignees (both universities and businesses).[9] The residual category, not shown, is patents by individual unaffiliated inventors. Most of the top twenty producing universities had their ag-biotech patents cited at about the same rate by businesses, universities and foreign inventors. The major exception is Rutgers University where 96 percent of the citing patents were owned by businesses.

Local Spillovers

Table 3 shows the proportion of these business citations that are localized in the same state as the university. Overall, the in-state business citations represent only 6.8% of all citations and 13% of the business citations. This demonstrates very low levels of in-state business citations, especially when one considers that one institution, Iowa State, accounts for more than one-third of the in-state citations. Iowa State's high level of localization reflects a very strong relationship between Pioneer Hybrid Seed Company and Iowa State University, rather than citations by start-up businesses.

Overall, the evidence suggests that while strong links exist between university ag-biotech patents and businesses, the degree of localization of those links to date has been quite small. While these data are by no means definitive because ag-biotech patenting is still in its beginning stages, they do suggest that ag-biotech is not following the same pattern of agglomeration effects seen in pharmaceutical biotechnology. To date, there seem to be relatively little new patentable research fostered in the proximate neighborhoods of Land Grant Universities. Instead, significant local business spillovers seem to take place where universities happen to be located in the same state as a major agribusiness companies (e.g. Pioneer in Iowa, and J. R. Simplot in Idaho) rather than visa-versa. The recent takeoff in ag-biotech patents, however, could possibly give rise to a distinctive pattern of citations by local businesses, as the technology enters a second wave of commercial development. Thus, more definitive answers to confirm the low degree of spillover localization found so far will require either more time to be revealed in the pattern of citations or university-level data on current start-up efforts.

F) Inequality in Patent Production Lorenz Curve Analysis

We use a Lorenz curve for the analysis of inequality among universities in ag-biotech patenting. The analysis here is restricted to Land Grant Universities, because universities that did not engage in any agricultural research would overstate levels of inequality in a sample of all universities. Figure 3 presents a Lorenz curve for university ag-biotech patenting comparing the period up until 1995 with the last four years. As the Lorenz curves show, there is a great deal of inequality with, for the full timeline, the top 10% of universities owning more than 35% of the patents and the top 20% owning almost 60%. While patenting in the last four years has become mildly less concentrated as more universities participate, the top universities still own a disproportionate number of ag-biotech patents.

Figure 4 uses citation counts in an attempt to adjust the patents for quality differences. These data show higher degrees of inequality, with even higher levels of inequality for recent patents. This finding suggests that the differences in patent quality are higher than those for measures of total patents. If that quality difference were also to show up in differences in patenting revenues, then one could expect to see increasing differences in university funding levels. This concern, however, can be partially tempered by our finding of no correlation between patent quantities and qualities.

Finally, we compare, in Figure 5, Lorenz curves for ag-biotech patenting to ones for agricultural college funding and numbers of graduate students in agricultural sciences. The figure shows that ag-biotech patenting to date has been more unequally distributed among universities than has either overall agricultural science funding or graduate student numbers. However, these differences between patenting and financing are not large. Whether they will persist is also unclear, especially if the recent widening in patent production continues. While not definitive, the evidence so far suggests that university ag-biotech patenting at the very least is not diminishing inequality among Land

Grant Universities and, if the imbalance in citations turns out to reflect revenue streams from ag-biotech research, may be increasing it.

V. Concluding Remarks

The time is ripe for empirical work that can inform land-grant university researchers and administrators as they participate in public policy discussions on how ag-biotech research and development should unfold in the U.S. and internationally. Luckily, as demonstrated in this paper, the ready availability of secondary sources of data, such as those from the U.S. Patent Office, make such research less complicated than is often imagined. The data provide a way to get started on the debate, by imparting key information needed to better understand trends in university ag-biotech research, patenting, and citations.

This study of university ag-biotech patents offers many useful lessons beyond simply identifying the scope of activity to date. One is the strong evidence for persistence in ag-biotech patent production. That finding bodes poorly for universities not already active in this arena that might be pursuing a catch-up strategy. So does the fact that both patents and citations are somewhat more concentrated among the leading Land Grant Universities than are research funding and graduate student enrollments in agricultural sciences. This finding buttresses the concerns of the potential that ag-biotech has for deepening the existing inequality among major and minor Land Grant Universities.

One finding from the patent and citation data, however, somewhat counterbalances potential concerns about persistence and inequality. We find no relationship between the quantity of patents held by a university and the importance of those patents, as indicated by the number of citations received. In other words, there seems to be an equal chance that a given patent will turn out to be a major discovery regardless of whether a university is a minor or major player in ag-biotech patenting. This suggests that patents are much like lotteries, where the probability of winning goes up with the number of tickets held but not the probability of any given ticket being a winner. While it is still too early to judge economic returns to university ag-biotech patents, the high citation rates suggest they are relatively more important for the research community than other university patents.

In terms of the potential spillover effects of ag-biotech patents, the citation data show that, while strong links exist between university ag-biotech patents and businesses, the degree of localization of those links to date may be quite small. Put differently, major international firms are the main businesses citing university ag-biotech patents. While not yet definitive, our research suggests that if university ag-biotech is going to generate significant local spillovers in the form of start-up companies to the extent that computers or pharmaceuticals have, it will have to occur in the subsequent rounds of patenting, because it has not occurred yet.

This analysis of U.S. patent data has offered preliminary evidence on several pressing questions in university ag-biotech patenting, but more research and data are needed. First, in focussing on patents, this inquiry has ignored the value of other ag-biotech research output, such as published papers, conference presentations, improved technical infrastructure, and a community of informed and skilled researchers and students. Second, while this work has used citations as a measure of quality, future research could improve on patent and citation measures with data on licensing revenues and university involvement in start-up companies. Finally, it remains to be seen to what extent commercial motives, either through direct industry financing or through the promise of patent revenues, influence the research at Land Grant Universities to be more applied and aimed at patents rather than toward basic fundamental research. Future research that investigated these issues would help further the debate.

While certainly not definitive, our analysis provides some guidance to federal and state policy makers and university administrators, as they develop policies and make investments in research. National policy makers should be heartened by the recent "take-off" in university ag-biotech research, the high quality of the patents, and the national public-good nature of the patents. On the national scale, however, additional support for new entrants and minor players in ag-biotech research may be warranted, since our results show that patenting in agricultural colleges is likely to foster inequalities among universities in part because of its path dependent feature.

In choosing among different potential focuses for university research, the higher average citation rate for ag-biotech patents compared to other university patents suggests that ag-biotech research may be a more valuable lottery to invest in than other types of patented research. Yet, the national or even international nature of spillovers or public goods created by university ag-biotech research to date raises questions about the likely efficacy of ongoing efforts by state governments to encourage local ag-biotech business ventures through sponsoring university research in this arena of inquiry. Ag-biotech patenting would seem to be a good investment, but policy makers should be aware that the benefits will not be equally distributed and may not land in the places envisioned.

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Figure 1. University Ag-Biotech Patent Production by Year

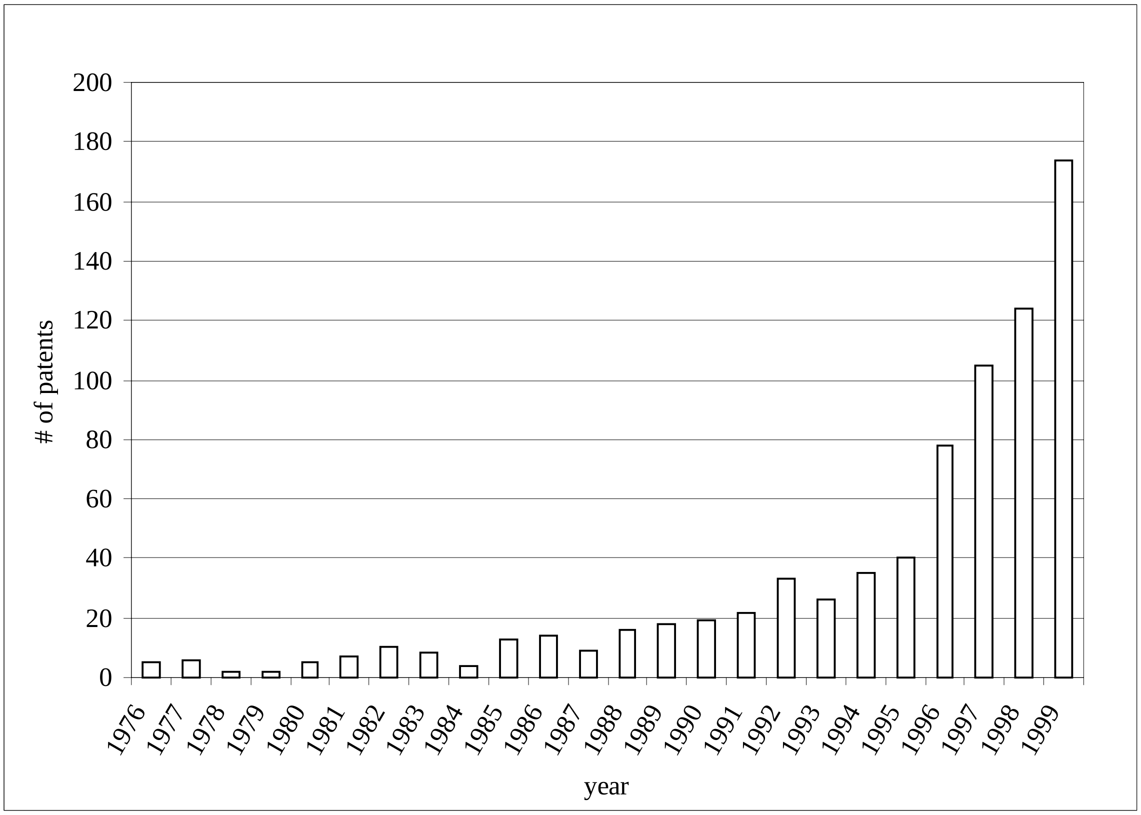


Table 1. University Ag-Biotech Patent Rankings

University	Ranking as of 2000	Number of Patents in 2000	Ranking as of 1995	Number of Patents in 1995
U. of Wisconsin	1	53	1	29
Cornell	2	52	2	21
Iowa State	3	47	5	11
Michigan State	4	44	12	7
UC-Davis	5	32	15	7
U. of Florida	6	29	3	14
Purdue	7	26	4	13
U. of Minnesota	8	26	14	7
Louisiana State	9	24	9	8
North Carolina State	10	21	7	10
Texas A&M	11	19	.	0
UC-Berkeley	12	19	6	11
Rutgers	13	18	.	0
U. of Georgia	14	17	10	8
Oregon State	15	14	8	10
U. of Maryland	16	13	11	8
U. of Pennsylvania	17	13	.	0
U. of Kentucky	18	12	.	0
Ohio State	19	11	13	7
Penn State	20	11	.	0
Total		795		294

Figure 2. Average Citations per Patent by Year

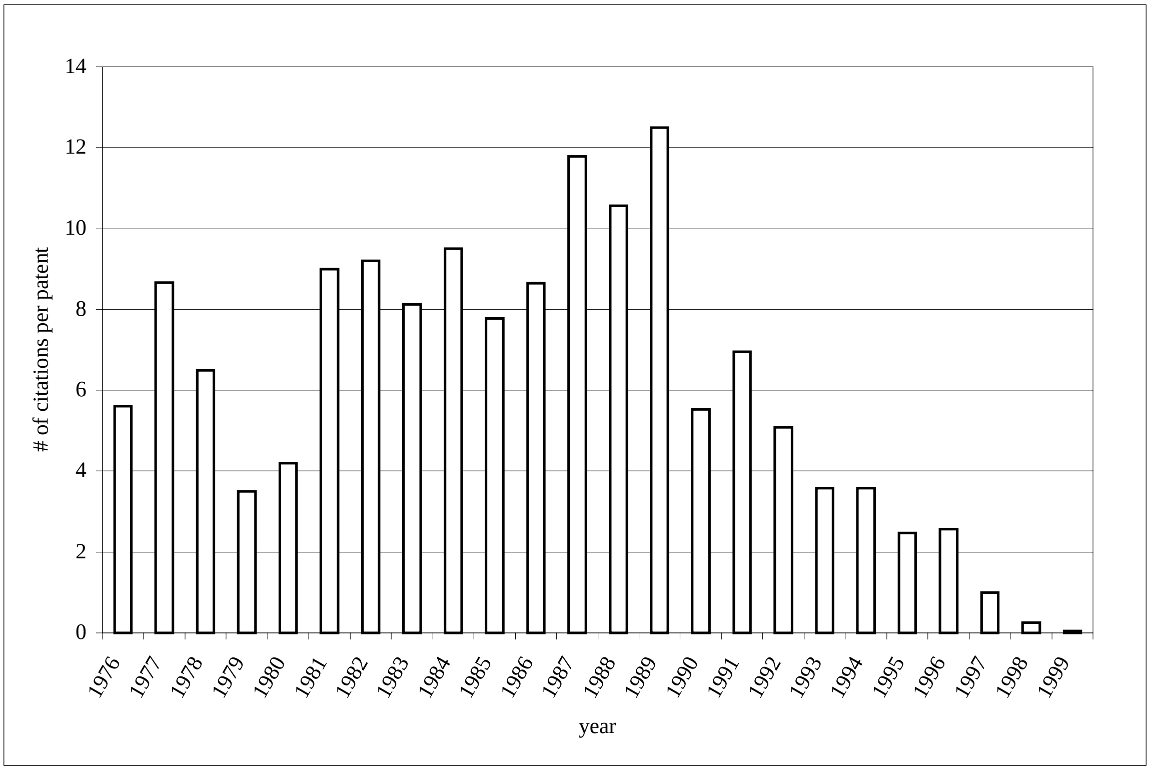


Table 2. Citations by the Top 20 Patenting Universities

University	**Total**	**Business**		**Universities**		**Foreign**	
	Citations	**No.**	**%**	**No.**	**%**	**No.**	**%**
U. of Wisconsin	186	93	50.0	74	39.8	15	8.1
Cornell	101	51	50.5	26	25.7	17	16.8
Iowa State	124	74	59.7	30	24.2	11	8.9
Michigan State	37	18	48.6	13	35.1	4	10.8
UC-Davis	47	13	27.7	14	29.8	19	40.4
U. of Florida	81	51	63.0	20	24.7	9	11.1
Purdue	76	44	57.9	14	18.4	15	19.7
U. of Minnesota	51	30	58.8	13	25.5	6	11.8
Louisiana State	37	13	35.1	20	54.1	4	10.8
North Carolina State	43	11	25.6	19	44.2	12	27.9
Texas A&M	45	23	51.1	19	42.2	3	6.7
UC-Berkeley	82	46	56.1	14	17.1	15	18.3
Rutgers	75	72	96.0	0	0.0	1	1.3
U. of Georgia	33	14	42.4	6	18.2	11	33.3
Oregon State	51	23	45.1	10	19.6	14	27.5
U. of Maryland	24	10	41.7	8	33.3	4	16.7
U. of Pennsylvania	3	1	33.3	1	33.3	0	0.0
U. of Kentucky	12	5	41.7	5	41.7	1	8.3
Ohio State	136	60	44.1	33	24.3	30	22.1
Penn State	5	1	20.0	1	20.0	3	60.0
Total	2188	1142	52.2	567	25.9	336	15.4

Table 3: Localization of Business Citations

University	Business					
	Out of State		In State		Total	
	No.	%	No.	%	No.	%
U. of Wisconsin	83	44.6	10	5.4	93	50.0
Cornell	46	45.5	5	5.0	51	50.5
Iowa State	21	16.9	53	42.7	74	59.7
Michigan State	18	48.6	0	0.0	18	48.6
UC-Davis	6	12.8	7	14.9	13	27.7
U. of Florida	49	60.5	2	2.5	51	63.0
Purdue	44	57.9	0	0.0	44	57.9
U. of Minnesota	27	52.9	3	5.9	30	58.8
Louisiana State	12	32.4	1	2.7	13	35.1
North Carolina State	9	20.9	2	4.7	11	25.6
Texas A&M	21	46.7	2	4.4	23	51.1
UC-Berkeley	37	45.1	9	11.0	46	56.1
Rutgers	72	96.0	0	0.0	72	96.0
U. of Georgia	14	42.4	0	0.0	14	42.4
Oregon State	22	43.1	1	2.0	23	45.1
U. of Maryland	9	37.5	1	4.2	10	41.7
U. of Pennsylvania	0	0.0	1	33.3	1	33.3
U. of Kentucky	5	41.7	0	0.0	5	41.7
Ohio State	59	43.4	1	0.7	60	44.1
Penn State	1	20.0	0	0.0	1	20.0
Total	993	45.4	149	6.8	1142	52.2

Figure 3. Lorenz Curves for Ag-Biotech Patents at Land Grant Universities

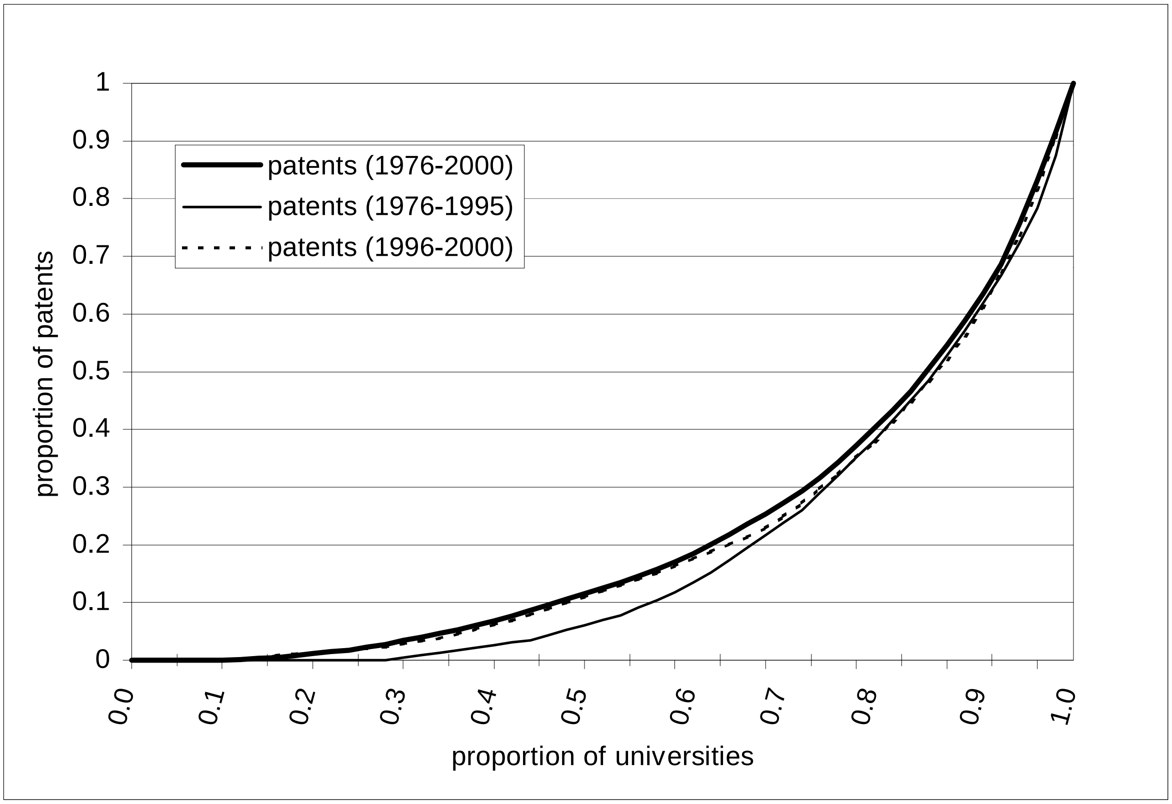


Figure 4. Lorenz Curves for Citations Received in Land Grant Universities

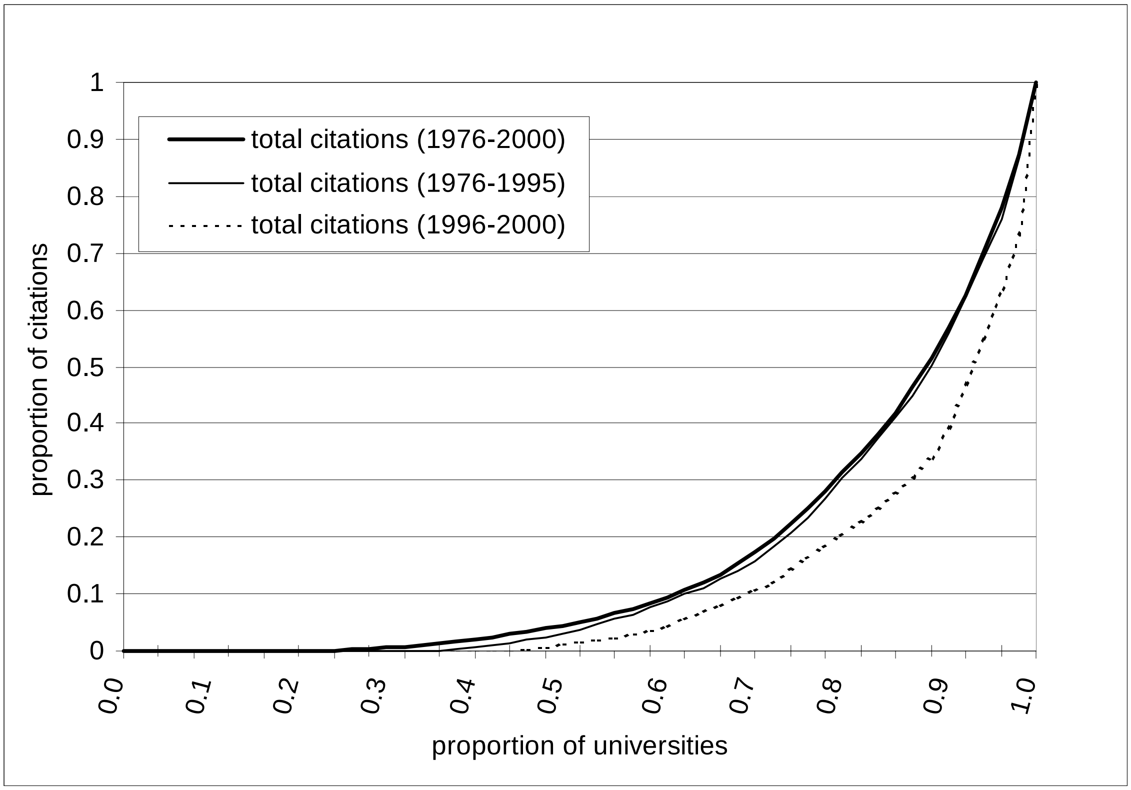
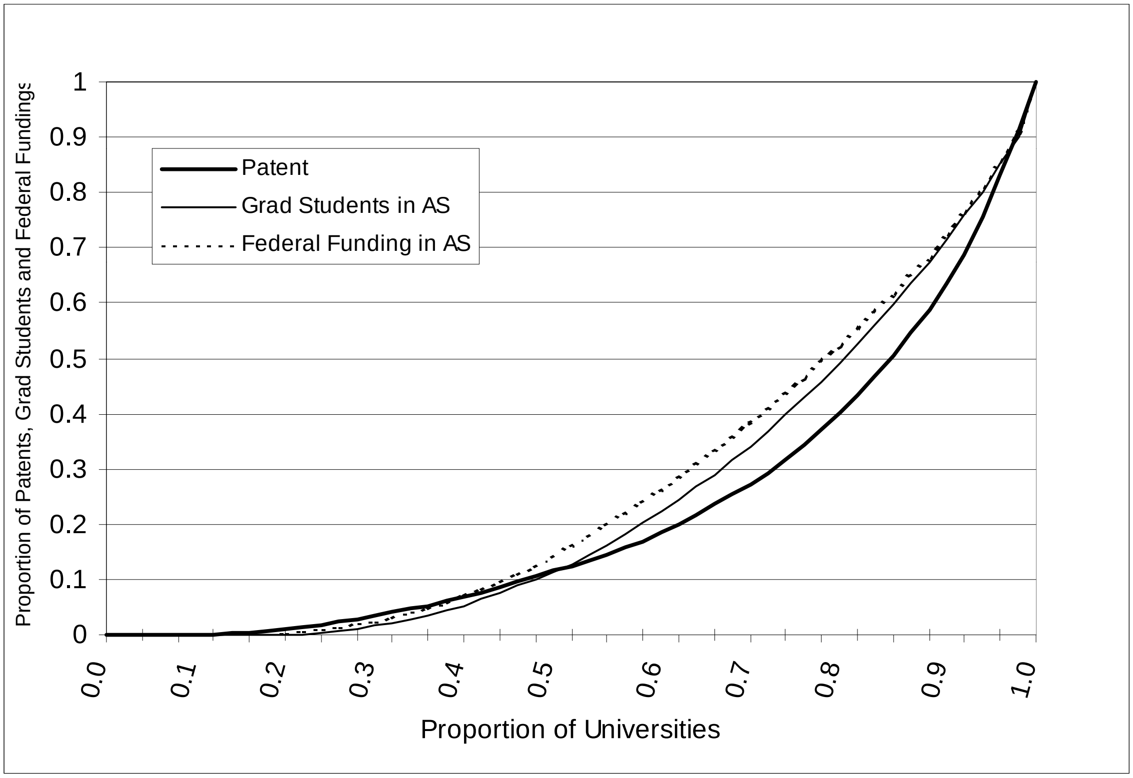


Figure 5. Lorenz Curves For Ag-Biotech Patents, Agricultural Graduate Students and Federal Funding in Agriculture among Land Grant Universities[10]



Endnotes

[1] For example attempts by the authors to get accurate counts from university patent offices showed differing definitions and a fuzzy knowledge on the part of technology transfer personnel on what could be considered ag-biotech. Also a recent conference of agricultural college Deans and Research directors concerned with ag-biotech issues included a heated, but data-free, discussion of who had more ag-biotech patents.

[2] While revenue data is not available, ag-biotech patent production maybe in too early a stage of production for it to be an accurate measure of value. Given the usual lag between patents and commercial development and the dramatic growth in the last four years, it is likely that revenues from these patents are still relatively low in most universities.

[3] Plant patents, under the plant variety protection act, were excluded because they represent a much lower level of intellectual property protection as well as lower levels of novelty required for a successful application.

[4] We do not distinguish between university and business patents for non-U.S. citations because of the different laws in determining what constitutes a university from a private company in other countries.

[5] We date patents by the year of grant unlike Foltz et al. (2001) and Henderson et al. (1998) who chose to date patents by the year of application to reduce time lags between the existence of new invention and grant date. In this study by crediting universities in the year of the patent grant we are able to minimize incomplete data issues.

[6] Cornell University is both a public and private institution, but the agricultural college is a land-grant institution and part of the public component of the institution.

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[7] For details on estimation approach, see Foltz, Kim and Barham (2001) which examines the factors that account for ag-biotech patenting success among universities using a dynamic count data model.

[8] For details on issues relating to the use of citation data to infer knowledge spillovers see Jaffe et al. (1993) and Jaffe et al. (2000).

[9] Note that university citations include 274 self-citations—a citing patents assigned to the same party as the originating patent. Thus, a higher proportion of citations outside the university are business citations of university patents, thereby suggesting an even stronger linkage between university patents and businesses than shown in the data.

[10] Data on agricultural graduate students and federal financing in agriculture from National Science Foundation (2000).