UNIVERSITIES AS A SOURCE OF COMMERCIAL TECHNOLOGY: A DETAILED ANALYSIS OF UNIVERSITY PATENTING, 1965–1988

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Abstract—This paper explores the recent explosion in university patenting as a source of insight into the changing relationship between the university and the private sector. Before the mid-1980s, university patents were more highly cited, and were cited by more diverse patents, than a random sample of all patents. More recently several significant shifts in university patenting behavior have led to the disappearance of this difference. Thus our results suggest that between 1965 and 1988 the rate of increase of important patents from universities was much less than their overall rate of increase of patenting.

I. Introduction

RECENT work in both macroeconomic theory and technology policy has focused renewed attention on the role of spillovers in general and on university research in particular in driving economic growth (Caballero and Jaffe (1993) and Romer (1986, 1990)). Since universities are in principle dedicated to the widespread dissemination of the results of their research, university spillovers are likely to be disproportionately large and may thus be disproportionately important (Dasgupta and David (1987), Jaffe (1989), Merton (1973), Zucker et al. (1997), and National Academy of Sciences (1995)).

This focus on university research comes at a time when universities have been under increasing pressure to translate the results of their work into privately appropriable knowledge. In 1980 and 1984 major changes in federal law made it significantly easier for universities to retain the property rights to inventions deriving from federally funded research. At the same time increasing competition for federal resources has forced many universities to turn to alternative sources of funding. Many universities have established technology licensing offices and are actively pursuing industrial support.

At first glance these changes appear to have had a dramatic effect on the way in which university research is transferred to the private sector. University patenting has exploded. In 1965 just 96 U.S. patents were granted to 28 U.S. universities or related institutions. In 1992 almost 1500 patents were granted to over 150 U.S. universities or related institutions. This 15-fold increase in university patenting occurred over an interval in which total U.S. patenting increased less than 50%, and patents granted to U.S. inventors remained roughly constant. However, the extent to which this explosion should be taken as evidence of a large increase in the contribution of universities to commercial technology development depends on the extent to which it represents more commercially useful inventions versus the extent to which it represents simply increased filing of patent applications on marginal inventions.

Received for publication September 5, 1995. Revision accepted for publication December 13, 1996.

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This paper explores this issue in some detail, both as a phenomenon of interest in its own right and as a window into the changing role of universities as sources of technology for the private economy. A number of surveys and some detailed case study work have documented substantial shifts in the nature of the relationship between universities and the private sector (Blumenthal (1986), Cohen et al. (1994), David et al. (1992), and National Science Foundation (1982)). Here we focus on university patents, both because patents are a unique and highly visible method of ''technology transfer'' (Archibugi (1992), Basberg (1987), Boitani and Ciciotti (1990), Schwartz (1988), and Trajtenberg (1990a)), and because their accessibility allows for a more comprehensive analysis than is possible with either surveys or case study work.

We draw on a comprehensive database consisting of *all* patents assigned to universities or related institutions from 1965 until mid-1992, a 1% random sample of all U.S. patents granted over the same time period, and the complete set of all patents that cite either of these groups. We show that averaged over the whole time period, university patents are both more important and more general than the average patent, but that this difference has been declining over time, so that by the late 1980s we cannot find significant differences between the university patent universe and the random sample of all patents. We suggest that the observed increase in university patenting may reflect an increase in their ''propensity to patent''—and possibly an associated increase in the rate of knowledge transfer to the private sector—rather than an increase in the output of ''important'' inventions.

The paper is organized into five sections. The following section describes our data, and explains some of the institutional changes that appear to be driving the growth of university patenting. Section III demonstrates the difference between university and other patents in the citation-based measures of importance, and the decline of that difference in the 1980s. Section IV explores possible explanations for that decline. Section V provides concluding observations.

II. The Growth of University Patents

A. The Basic Numbers

This paper is part of a larger research project that exploits the declining cost of access to large quantities of patent data. In prior work we have used patent data to show that spillovers are geographically localized (Jaffe et al. (1993)), that spillovers from university research are less likely to be geographically localized than privately funded research (Henderson et al. (1996)), and to explore the degree to which citation-based measures provide useful information about the scientific and economic impact of the idea captured in a patent (Trajtenberg et al. (1996)). Here we draw on these data to explore how the quantity and ''quality'' of university patents have changed over time, and to compare both to the overall universe of U.S. patents.[1]

We use four sets of patents: all university patents granted between 1965 and mid-1992 (12,804 patents); a 1% random sample of all U.S. patents[2] over the same period (19,535 patents); all patents after 1974 that cited the university patents (40,859 patents), and all patents after 1974 that cited the random sample patents (42,147 patents).[3] For these patents we know the year of application,[4] the identity of the institution to which it is assigned, and the ''patent class,'' a detailed technological classification provided by the patent office.

Figure 1 illustrates the dramatic increase in patenting we have already described. Panel A compares the rate of university patenting to all U.S. patents and to domestic U.S. patents. Panel B shows university patenting relative to university research, and an analogous ratio for the U.S. industrial sector. University patenting has not only increased, it has increased more rapidly than overall patenting and much more rapidly than domestic patenting, which is essentially flat until the late 1980s. In addition, university patenting has increased more rapidly than university research spending, causing the ratio of university patents to R&D to more than triple over the period. In contrast the ratio of domestic patents to domestic R&D nearly halved over the same period. Thus universities' ''propensity to patent'' has been rising significantly at the same time that the overall propensity to patent has been falling. Note that the increase in university patenting has been fairly continuous since the early 1970s. There is some evidence of an acceleration in the late 1980s, but this is a period in which both university research and overall patenting accelerate as well, making it difficult to assess its significance.

This increasing propensity to patent is also evident in a significant increase in the number of universities taking out patents. Whereas in 1965 about 30 universities obtained patents, in 1991 patents were granted to about 150 universities and related institutions. Nevertheless, university patenting remains highly concentrated, with the top 20 institutions receiving about 70% of the total, and MIT, the most prolifically patenting institution, alone receiving about 8%. The top 10 institutions and their total patent grants for 1991 are shown in table 1.

FIGURE 1.—INCREASE IN PATENTING

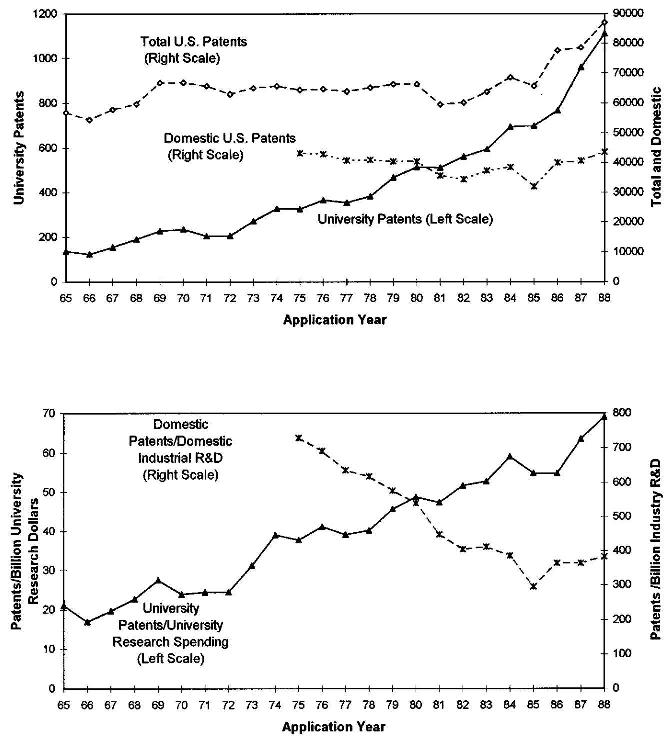


TABLE 1.—TOP 10 INSTITUTIONS FOR UNIVERSITY PATENTS, 1991

Institution	Patent Count
Massachusetts Institute of Technology	100
University of California	91
University of Texas	82
Stanford University	56
Wisconsin Alumni Research Foundation	44
University of Florida	43
Iowa State University Research Foundation Inc.	39
California Institute of Technology	32
University of Minnesota	30
Johns Hopkins University	26

The increase in university patenting has not been uniform across the spectrum of technologies. Panel A of figure 2 shows the breakdown of university patents by field over time,[5] panel B shows it for all patents.[6] The differences are dramatic, if not surprising. By the end of the 1980s, drug and medical patents comprised about 35% of the university total,

[1] In our earlier paper (Henderson et al. (1996)) we documented the existence of a decline in the ''quality'' of university patents. However, in that paper we were not able to control for problems such as truncation bias or shifts in citation patterns over time, and we were not able to explore the causes of the decline in any detail.

[2] By ''U.S. patents'' we mean patents granted by the U.S. Patent Office. By the end of this period, about half of such patents were granted to non-U.S. residents. About 1% of the patents assigned to U.S. universities were taken out by individuals who gave the patent office non-U.S. addresses.

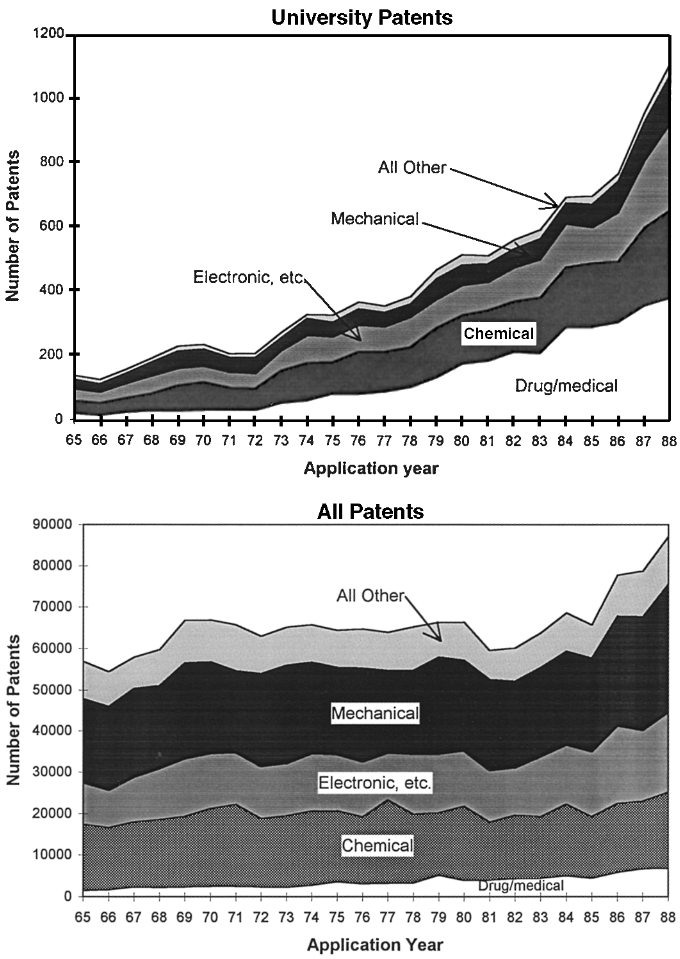
[3] A detailed description of the data set is given, Henderson et al. (1995) or is available from the authors as a technical appendix.

[4] We prefer to date patents by the year of application rather than the year of grant, because that is when the inventor identified the existence of a new invention, and there are variable lags involved between application and grant date. Because of these lags, however, totals by date of application are incomplete for years approaching the 1992 data cutoff date, since some patents applied for at the end of the period were almost certainly still under review at the time we collected our data. Thus we terminate our time-sensitive analyses in 1988.

[5] Full details of this classification by field are given in Jaffe (1986).

[6] This and all subsequent analyses are based on our 1/100 random sample of all patents. Given the large number of such patents (over 500 per year), the composition by field of the sample is very likely to be close to the composition by field of the universe of all patents. Note that the random sample does *not* exclude university patents. Even at the end of the period, however, university patents are less than 2% of the total.

FIGURE 2.—PATENTS BY BROAD FIELDS



up from less than 15% in 1965; chemical patents 25–30%; electronic and related patents 20–25%; mechanical patents 10–15%; and about 5% other. In contrast, overall patenting is 30–35% mechanical; 20–25% each for chemical and electronics, 10–15% other; and less than 10% drugs and medical. Thus universities are much more interested in drugs and medical technologies, and much less interested in mechanical technologies, than other inventors, and the difference has increased over time.

B. The Broader Context of Increased University Patenting

There are several possible explanations for this dramatic increase in patenting behavior. Changes in federal law affecting university patenting in 1980 and then again in 1984 made it significantly easier for universities to patent the results of federally funded research. Industry funding of university research has notably increased and at the same time there has been a substantial increase in organized university ''technology transfer'' or ''licensing'' offices. Since all three changes occurred roughly simultaneously, their different effects cannot be easily separated, but it seems plausible that all three have played an important role in increasing the number of university patents.

Federal Law Affecting University Patenting: Before 1980 the federal government had the right to claim all royalties or other income derived from patents resulting from federally funded research. Federally funded researchers could apply for patents, and could assign those patents to universities, but the exclusive property right associated with the invention remained with the government whether or not a patent was issued. The only way that a university could profit from federally derived patents was to seek a title rights waiver from the funding agency. Since approximately 70% of university research during this period was funded by the federal government, this was a major barrier to widespread university patenting.

In 1980 Congress passed The Patent and Trademark Amendments of 1980 (Public Law 96-517), also known as the Bayh-Dole Act. The Bayh-Dole Act gave universities (and other nonprofit institutions, as well as small businesses) the right to retain the property rights to inventions deriving from federally funded research. The 1984 passage of Public Law 98-620 expanded the rights of universities further by removing certain restrictions contained in the Bayh-Dole Act regarding the kinds of inventions that universities could own, and the rights of universities to assign their property rights to other parties.

Thus since 1984 universities have had very broad rights to exploit inventions derived from their research, even if it is federally funded. They can charge royalties for the use of the patent, and they can assign the patent to a third party if they so desire. As a result, major research universities now typically have explicit policies requiring faculty and other researchers to assign patents deriving from on-campus research to the university, and specifying how any income deriving therefrom is to be divided among the institution, the researcher, and research centers or departments.

Increase in Organized University "Technology" Offices: Though it is obviously difficult to separate the chicken from the egg, since the passage of the Bayh-Dole Act there has been a dramatic increase in the scale and significance of the patenting and technology licensing function at universities. The Association of University Technology Administrators (AUTM) has recently begun conducting surveys of its members. The surveyed institutions[7] employed 767 full-time equivalent professional employees in technology transfer and licensing activities. In 1993 they received royalties totaling about $375 million on about 4016 licensing agreements; more than 4000 additional active agreements were not currently generating revenue.[8]

[7] Survey responses came from 112 U.S. institutions that were granted 1169 patents in Fiscal Year 1992, compared to our data, which indicate that about 1500 patents were granted to over 150 institutions. Thus survey totals are lower bounds on the actual numbers.

[8] *The AUTM Licensing Survey, Fiscal Years 1991, 1992, and 1993.* AUTM categories included in the quoted totals are U.S. universities, U.S. hospitals, third-party management firms, and research institutes. Excluded are government and Canadian universities. The royalty total has been adjusted to eliminate double counting, which results from shared license agreements (personal communication, Ashley Stevens, AUTM).

TABLE 2.—CORRELATION COEFFICIENTS ACROSS KEY PATENT-RELATED VARIABLES, 1993 DATA

	FTEs for Licensing Activities	Disclosures	Gross Royalties	Industry Support	Public Support
Total U.S. patents filed	0.88 (113)	0.91 (112)	0.71 (112)	0.69 (110)	0.82 (113)
FTEs		0.84 (112)	0.81 (112)	0.61 (110)	0.86 (113)
Disclosures			0.72 (112)	0.66 (109)	0.83 (112)
Royalties				0.53 (109)	0.71 (112)
Industry support					0.64 (110)

Source: *The AUTM Licensing Survey.*
Notes: Figures in parentheses are number of observations. The number of observations varies because not all universities participating in the survey provide comprehensive data.

Increased Industry Funding of University Research: Another factor that may be related to the increase in university patenting is an increase in industry funding of university research from 2.6% in 1970 to 3.9% in 1980 and 7.1% in 1994.[9]

It is clearly impossible to assign the roles of "cause" and "effect" to these different trends. The increase in university patenting predates the passage of the Bayh-Dole Act, but continued exponential growth probably could not have been sustained without removal of the cumbersome barriers to patents from federal research. The increase in universities' institutional commitment to patenting, in the form of new and expanded licensing offices, would likely not have occurred if the impetus toward more commercial research and the change in federal law had not occurred. But once created, these offices presumably facilitate the patent application process and thereby contribute to the increased patenting. Finally, increased industry funding is probably partially a response to universities' increased interest in applied research, but it, in turn, increases the resources for these activities and thereby also supports increased patenting.

Table 2 illustrates this close correlation quantitatively. For the 113 universities reporting comprehensive data to AUTM it presents correlations across patenting rates, employees in the licensing office, invention disclosures, gross royalities, and the level of industrial and publicly funded support. In these cross-sectional data patenting rates are less correlated with levels of industry funding than with levels of public funding, disclosure rates, or the size of the licensing office, suggesting that increased industry funding may be less important in driving patenting behavior than changes in the law and the expansion of technology licensing offices, but the high degree of serial correlation evident in the raw longitudinal data make it impossible to draw any firm conclusions as to the relative importance of these various factors.

III. Characterizing University Patenting

A. *Citation-Based Measures of Importance and Generality*

The flow of technology out of universities almost certainly contributes to technological innovation in the private sector (Jaffe (1989)), and there is a widespread belief that more effective transfer of technology from universities to the private sector would be beneficial to innovation and growth (U.S. GAO (1987) and National Academy of Sciences (1995)). In this light, to the extent that it signals an increase in the successful commercial application of university-derived technology, the rapid increase in university patenting would appear to be a highly desirable trend. However, patents vary tremendously in their importance, making it dangerous to draw conclusions about aggregate technology flows based on numbers of patents (Griliches (1990)). In this section we look more carefully at the university patents, to understand better what the patent data do and do not say about increases in the flow of technology out of universities.

In an earlier paper (Trajtenberg et al. (1996)) we used patent citation data to construct a variety of measures that we interpreted as capturing the importance or "basicness" of the invention covered by a patent. Implicit in this approach is a view of technology as an evolutionary process, in which the significance of any particular invention is evidenced, at least partly, by its role in stimulating and facilitating future inventions. We assume that at least some of such future inventions will reference or cite the original invention in their patents, thereby making the number and character of citations received a valid indicator of the technological importance of an invention (Trajtenberg (1990a) and Carpenter and Narin (1993)).[10]

[9] With federal funding at 60 to 70% of the total, the remainder is funded by state and local governments and institutions' own funds.

[10] Citations or references serve the legal function of delimiting the scope of patent protection by identifying technological predecessors of the

We use two citation-based measures: *importance* and *generality.* We define importance as

$$Importance_i = Nciting_i + \lambda \sum_{j=1}^{Nciting_i} Nciting_{i+1,j}$$

where $0 < \lambda < 1$ is defined as an arbitrary discount factor, which in the previous paper we set to 0.5. In the absence of data about ''second-generation'' citations in the data set on which this paper relies, we here set λ equal to zero and measure importance simply by total citations received.

The second citation-based measure that we use is *generality.* We hypothesize that patents that cover more ''basic'' research will be cited by work in a broader range of fields, and define generality as

$$General_i = 1 - \sum_{k=1}^{N_i} \left(\frac{Nciting_{ik}}{Nciting_i}\right)^2$$

where k is the index of patent classes and N_i is the number of different classes to which the citing patents belong. Notice that $0 \leq General \leq 1$, and that higher values represent less concentration and hence more generality. In our previous paper we were able to show that both of these measures were reassuringly high for a number of patents that are known to have had a very significant impact on their field.

Citation-based measures of importance and generality are, to some extent, influenced by variations in citation practices across time and technological areas. They are also very influenced by the fact that when we count the citations of a patent issued in, for example, 1989, we are missing many more of the citations that it will ultimately receive than we are missing in our count of the citations of a patent issued in 1975. For these reasons, when comparing importance or generality it is necessary to control for both time and technological field effects.

B. *Comparing University and Random Sample Patents*

As a first step in exploring the degree to which the increase in university patenting rates reflects an increasing transfer of knowledge to the private sector, we first explore the degree to which university patents are more important or more general than the random sample of patents and the degree to which this has changed over time.

Table 3 presents the results of regressions of our measures of importance and generality on a series of dummy variables for application years and technological areas, and dummy variables for whether or not the original patent was a university patent. These regressions are based on application years 1965–1988 for importance and 1975–1988 for generality.[11] Over the entire period, controlling for technological field effects and time effects, university patents received almost 25% more citations on average, and this difference is highly significant statistically. They were also about 15% more general, again a statistically significant difference. These overall averages conceal a moderate amount of variation across fields. The difference between university and random sample patents is largest in electronics and mechanical patents, and smallest in the drug/medical area.

These results control for time effects, but they do not allow the university/random sample difference itself to vary over time. Results of regressions that allow each year cohort of patents to have its own university/random sample difference are shown in table 4 and again graphically in figure 3.[12] While the year-by-year differences are somewhat noisy, there is a clear overall trend: the university/random sample difference grew during the 1970s, reached a plateau during the period from about 1975 through about 1982, and fell significantly after that. The differences between the two

TABLE 3.—COMPARISON OF UNIVERSITY AND RANDOM SAMPLE PATENTS

	Importance 1965–1988 $n = 28{,}313$	Generality 1975–1988 $n = 14{,}775$
Random sample mean		
Drug/medical	4.00	0.258
Chemical	3.87	0.296
Electronics, etc.	4.23	0.288
Mechanical	3.77	0.265
All other	3.47	0.203
Overall university difference, controlling for field	0.918 (0.072)	0.0452 (0.0049)
University difference by field		
Drug/medical	0.311 (0.199)	−0.0168 (0.0135)
Chemical	0.416 (0.124)	0.0480 (0.0087)
Electronics, etc.	1.718 (0.141)	0.0582 (0.0094)
Mechanical	1.290 (0.153)	0.0740 (0.0107)
All other	0.396 (0.255)	0.0148 (0.0180)

Notes: Standard errors are in parentheses. Differences are estimated controlling for application-year effects.

patented invention. Thus if patent 2 cites patent 1, it implies that patent 1 represents a piece of previously existing knowledge upon which patent 2 builds, and over which patent 2 cannot have a claim. The applicant has a legal duty to disclose any knowledge of the prior art, but the decision as to which patents to cite ultimately rests with the patent examiner, who is supposed to be an expert in the area and hence to be able to identify relevant prior art that the applicant misses or conceals. Trajtenberg (1990a,b) showed that citation-weighted patents were a good proxy for the consumers' surplus generated by inventions. For more discussion of the value and limitations of citation data, see Trajtenberg et al. (1996).

[11] The generality measure cannot be calculated for the pre-1975 patents because we lack information on the citing patents before 1975, and we terminate the analysis in 1988 because a significant fraction of 1989 applications might be granted after mid-1992, when our data end. Also, those granted in 1990 and 1991 would have very little time to receive citations.

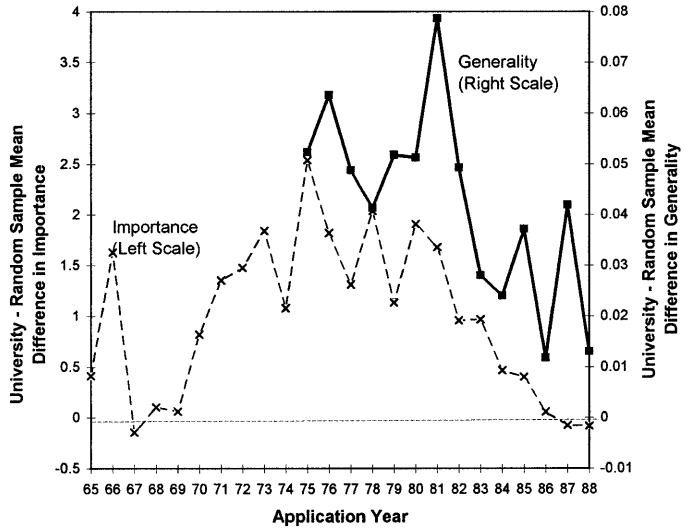
[12] To make sure that the university/random sample difference is not due to the different technological foci of the two samples, the regressions reported in table 4 replace the five technology field dummies used in table 2 with 364 separate dummies for patent office patent classes.

TABLE 4.—COMPARISON OF UNIVERSITY AND RANDOM SAMPLE PATENTS OVER TIME

Year	University/Random Sample Mean Difference Importance (1)	University/Random Sample Mean Difference Generality (2)
1965	0.42 (0.29)	
1966	1.63[a] (0.52)	
1967	−0.15 (0.41)	
1968	0.10 (0.35)	
1969	0.06 (0.44)	
1970	0.82[b] (0.42)	
1971	1.35[a] (0.41)	
1972	1.48[a] (0.41)	
1973	1.84[a] (0.38)	
1974	1.08[a] (0.35)	
1975	2.54[a] (0.35)	0.053[a] (0.019)
1976	1.82[a] (0.34)	0.065[a] (0.019)
1977	1.31[a] (0.34)	0.048[a] (0.020)
1978	2.04[a] (0.34)	0.040[b] (0.019)
1979	1.13[a] (0.31)	0.052[a] (0.018)
1980	1.91[a] (0.31)	0.051[a] (0.017)
1981	1.68[a] (0.31)	0.080[a] (0.018)
1982	0.96[a] (0.31)	0.051[a] (0.018)
1983	0.97[a] (0.30)	0.028[c] (0.017)
1984	0.47[c] (0.28)	0.024 (0.017)
1985	0.40 (0.28)	0.037[b] (0.017)
1986	0.06 (0.27)	0.013 (0.017)
1987	−0.07 (0.25)	0.043[a] (0.017)
1988	−0.08 (0.24)	0.012 (0.019)
Year Dummies	Significant	Significant
Patent class controls	Significant	Significant

Notes: [a] Significant at the 1% level.
[b] Significant at the 5% level.
[c] Significant at the 10% level.

FIGURE 3.—UNIVERSITY RANDOM SAMPLE CONTRAST OVER TIME



groups are statistically significant between 1970 (1975 for generality) and about 1982 or 1983. After that the two groups are not statistically different from one another in either generality or importance.

C. Robustness of the Apparent Decline

This decline in relative importance and generality appears to be robust to a number of factors, including truncation bias or possible shifts in citation patterns over time.[13] In the first place, they are robust to time–field interaction effects. If it were the case, for example, that drug patents have become increasingly less citation intensive over time, then university patents (which are increasingly concentrated in the drug/medical area) would appear to be increasingly less important in the sense of receiving fewer citations, because the regressions reported in table 4 control only for the *average* level of citations in drug-related patent classes. However, rerunning the regressions of table 4 *separately* for each of the five major fields yields results (not reported here) that suggest that the decline in the university advantage occurs across all fields and is thus not a result of any difference in composition by field across the two groups.

A second possibility is that the decline is an artifact of the truncation of the citation information in 1992. There are a number of reasons to suspect that such bias could be present. Suppose, first, that the pattern of the distribution of citations over time is identical for both university and random sample patents, but that in every year university patents receive proportionately more citations. Thus it might take several years for the cumulative difference between university and other patents to become significant, and the apparent disappearance of the difference between the two groups at the end of the observed period could simply reflect the fact that there has been insufficient time for the difference between the two

[13] Details of the analyses summarized in this subsection are given in Henderson et al. (1995) or are available from the authors.

groups to become apparent. However, a simple test of this idea—rerunning the regression in logs, thereby capturing the *proportionate* difference between the two groups rather than the absolute difference—produces results, (not reproduced here) that are broadly consistent with those reported above.[14] Thus the results probably cannot be explained by truncation of lag distributions, if the two distributions have the same shape.

A third, more subtle possible problem is that university patents may on average come later than those for private firms, so that the truncation has a more severe effect on them than on the random sample patents. However, a regression that estimates the difference between the average university and random sample patents in a given year, controlling for the predicted levels based on the years remaining to truncation and the average citation lag structure for each sample, gives very similar results to the simpler ones reported earlier, with the university/corporate difference declining sharply around 1981 or 1982 and becoming statistically insignificant shortly thereafter.

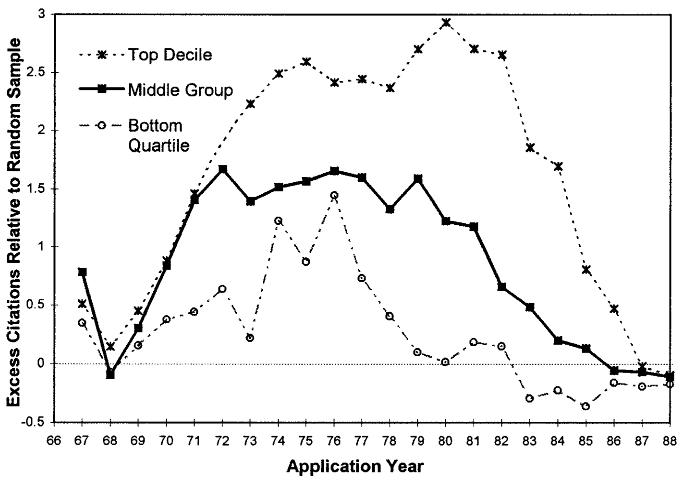
In summary, then, university patents in all fields were more important and more general than average in the 1970s. This advantage disappeared in all fields by the mid-1980s; and this disappearance does not appear to be an artifact of truncation or of the way in which citation patterns have changed over time.

IV. The Nature of the Decline

What, then may be causing this decline? One logically plausible candidate—the increasing importance of nonuniversity patents—can probably be easily dismissed, given that, as shown in figure 1, the late 1980s were a time of increasing propensity to patent. The overall patent/R&D ratio, which had been falling for most of this century, began to rise slightly, probably in response to the creation of a special court of appeals for hearing patent cases, and the issuance of several decisions that have increased the perceived likelihood that patents will be enforced (Schwartz (1988)). We suspect that these changes have made patenting slightly more attractive, all other things equal, thus making it economic to patent ideas of lower expected quality and thereby *reducing* the overall importance of private sector patents.

Our results suggest instead that the decline in the relative importance and generality of university patents had two principal components. First the fact that an increasing fraction of university patents is coming from smaller institutions, which have always produced patents that were not as highly cited as those from the larger institutions, and second a general decline in average quality that encompasses even the best institutions triggered largely by a large increase in the number of patents that receive no citations at all.

FIGURE 4.—CITATION INTENSITY OF UNIVERSITY PATENTS RELATIVE TO RANDOM SAMPLE OVER TIME BY PATENT RANKING OF INSTITUTION IN 1988



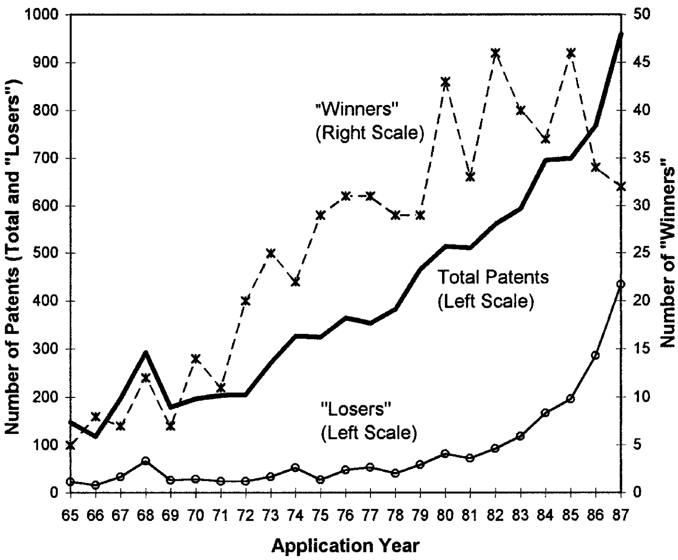
Notes: Top decile—top 10% of institutions in terms of patents in 1988; bottom quartile—bottom quartile in 1988 plus institutions that had no patents in 1988; middle group—everyone else.

Simple counts suggest that smaller institutions are indeed patenting more intensively. Since 1965 the fraction of patents going to the top four institutions has fallen from about 50% to about 25%. The Herfindahl index of concentration across institutions has also declined, from about 0.1 in 1965 to about 0.04 in 1988. These smaller institutions are indeed getting less important patents. Figure 4 shows the results of running regressions analogous to that underlying figure 3, but allowing the difference between university and random sample patents to differ not only over time but also according to the size of the institution. To control for size we grouped all institutions that got any patents over the period into three categories: (1) those institutions in the top decile in terms of the number of successful patent applications in 1988;[15] (2) those institutions that got fewer patents than the top decile but more than the bottom quartile in 1988; and (3) those institutions that were in the bottom quartile in terms of patent total in 1988 plus those that had no successful applications in 1988 but received at least one patent from some other year. The results are illustrated in figure 4. The results show that, except possibly for a few years in the second half of the 1970s, the bottom group of universities never produced patents that were statistically distinguishable from the random sample, whereas the 15 schools that comprise the top decile of institutions had patents that were even more superior to the random sample than those of other universities. Thus the fact that an increasing fraction of university patents is coming from smaller institutions does indeed seem to be partially responsible for the overall decline in the average importance of university patents. Notice that figure 4 also suggests, however, that even the

[14] This requires eliminating from both groups those patents with zero citations. The overall difference in importance between the two groups is about 15%. This overall difference conceals variation, with a high of about 30% in the mid to late 1970s, falling to insignificance by 1984.

[15] The distribution of patenting activities across universities is very stable over time, so that the choice of a particular year to divide the sample—in this case 1988—seems unlikely to introduce any particular bias into the results.

FIGURE 5.—TOTAL UNIVERSITY PATENTS, "WINNERS," AND "LOSERS"



Notes: Losers—patents with no citations by end of period; winners—patents with more citations than mean of top 10% of random sample patents from same year.

very best institutions have seen a decline in the relative quality of their patents since about 1983.

The second major component of the decline in average quality appears to be the presence of an increasing number of "low quality" university patents as the institutional changes that we outlined above have substantially increased universities' propensity to patent. Figure 5 illustrates this trend dramatically. It shows the overall increase in patenting (the heavy middle line), juxtaposed with two contrasting components of that total.

The dashed line at the top is the number of high-importance patents, dubbed "winners" in the graph and plotted on the right-side axis. This is the number of patents that received more citations than the mean of the top 10% of random sample patents from the same year. This series increases *faster* than the overall total up until the early 1980s, implying that the proportion of very important patents was increasing over this period. From 1981 on, however, this series fluctuates up and down with no clear trend and despite the approximate doubling in the total number of patents after 1980, there is no increase in the number of very important patents.

The bottom line is the number of "losers"—the number of patents each year that received no citations. It is virtually flat until the early 1980s, showing that the roughly fivefold increase in overall patenting up until that time was not accompanied by much of an increase in the number of these low-importance patents. After about 1981, however, this number increases dramatically, until by 1987 nearly half of all university patents are receiving no citations. This increase appears to reflect a real change in the composition of university patents, and is quite robust to controls for both field and truncation bias.

V. Conclusion

We have shown that the relative importance and generality of university patents has fallen at the same time as the sheer number of university patents has increased. This decrease appears to be largely the result of a very rapid increase in the number of "low-quality" patents being granted to universities.

What are the policy implications of this result? From a theoretical perspective, the Bayh-Dole Act and the increase in industry funding had two distinct effects on university incentives. Both the incentive to perform research that could be expected to produce important commercial inventions, and the incentive to patent and license whatever commercial inventions were produced increased. Clearly, the Bayh-Dole Act has been a success with respect to the second of these incentive effects. Both the rate of patenting and the extent of licensing have increased dramatically. In this context it is important to emphasize that even thought the body of uncited university patents that we have observed is probably less valuable *per patent* than previous university patents, these patents are not worthless in the aggregate. Some of these uncited patents are licensed and are commercially valuable. Before the Bayh-Dole Act they would probably not have been either patented or licensed, and the invention underlying them would have been unlikely to generate commercial benefits. Thus the increase in university patenting probably reflects an increased rate of technology transfer to the private sector, and this has probably increased the social rate of return to university research.

In contrast to the impact on the *transfer* of technology, our results suggest, however, that the Bayh-Dole Act and the other related changes in federal law and institutional capability have not had a significant impact on the underlying rate of *generation* of commercially important inventions at universities. Universities either did not significantly shift their research efforts toward areas likely to produce commercial inventions, or, if they did, they did so unsuccessfully. It is unclear, of course, whether it would be socially desirable if universities shifted their research efforts toward commercial objectives. It is likely that the bulk of the economic benefits of university research come from inventions in the private sector that build upon the scientific and engineering base created by university research, rather than from commercial inventions generated directly by universities. In other words, if commercial inventions are inherently only a secondary product of university research, then it makes sense for policy to seek to ensure that those inventions that do appear are transferred to the private sector, but not to hope to increase significantly the rate at which university research directly generates commercial inventions. This appears to be what has occurred.

From a methodological perspective, our results show that it is possible to use citations to improve the usefulness of patent statistics as economic indicators. The economic usefulness of these widely available data has been limited by their perceived noisiness. Even in the time-series dimension, where cohort effects and truncation bias make citation comparisons difficult, the use of a reference group and careful controls for technology field allowed us to produce fairly clear results regarding the changing nature of university patents. We believe that this technique can be readily applied to other data, thereby greatly increasing the signal-to-noise ratio in patent data.

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