Changes in University Patent Quality after the Bayh-Dole Act: A Re-Examination

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ABSTRACT:
The Bayh-Dole Act of 1980 facilitated the retention by universities of patent rights resulting from government funded academic research, thus encouraging university entry into patenting and licensing. Though the Act is widely recognized to be a major change in federal policy towards academic research, surprisingly little empirical analysis has been directed at assessing its impacts on the academy and on university-industry research relationships. An important exception is the work of Henderson, Jaffe and Trajtenberg (1998) which examined the impact of Bayh-Dole on the quality of university patents, as measured by the number of times they are cited in subsequent patents. The authors found that the quality of academic patents declined dramatically after Bayh-Dole, a finding that has potentially important policy implications. In this paper, we revisit those influential findings. By using a longer stream of patent citations data, we show that the results of the Henderson, Jaffe, and Trajtenberg study reflect changes in the intertemporal distribution of citations to university patents, rather than a significant change in the total number of citations these patents eventually receive. This has important implications not only for the evaluation of Bayh-Dole, but also for future research using patent citations as economic indicators.

JEL Codes: O3: Technological Change

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1. Introduction

The Bayh-Dole Act of 1980 created a uniform federal patent policy that allowed universities to retain rights to any patents resulting from government funded research and to license these patents on an exclusive or non-exclusive basis. Prior to the passage of the Act, universities wishing to retain title to patents resulting from federally funded research utilized Institutional Patent Arrangements (IPAs) that were negotiated with individual funding agencies or petitioned these agencies for title on a case-by-case basis. Bayh-Dole was passed in the throes of the "competitiveness crisis" of the 1970s and 1980s in the belief that the requirement to obtain IPAs or waivers and the frequently inconsistent policies of federal funding agencies regarding these agreements (especially regarding exclusive licensing) impeded technology transfer and commercialization of federally funded research results. In particular, the framers of this legislation argued that if universities could not be granted clear title to patents that allowed them to license rights to patented inventions exclusively, firms would lack the incentive to develop and commercialize university inventions.[1]

The Bayh-Dole Act has been widely cited (on the basis of slim evidence) as an important factor in the "competitive revival" of the U.S. economy during the 1990s (Association of University Technology Managers 1998, General Accounting Office 1998, Congressional Joint Economic Committee, 2000), and other countries are currently considering (or have recently enacted) similar legislation.[2] Some observers, however, have expressed concern that the

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[1] This argument was based on "evidence" that government-owned patents had lower utilization rates than those held by contractors, evidence that Eisenberg (1996) has shown to be faulty. The supporters of Bayh-Dole interpreted these data as indicators of the economic impact of academic research, neglecting the range of other formal and informal channels through which firms historically benefited from university research. In opening the Senate hearings, one of the architects of the legislation, Senator Birch Bayh (D. Indiana), cited the low rate of commercialization of government owned patents as evidence of "very little return on the billions of dollars we spend every year on research and development" (Senate Committee on the Judiciary 1979, p. 2).

[2] A recent report by the Organization of Economic Cooperation and Development (OECD) notes "[I]n nearly all OECD countries there has been a marked trend towards transferring ownership of publicly funded research from the

incentives created by Bayh-Dole may have shifted the academic research towards more "applied" work and away from fundamental research, a development with potentially detrimental long-term effects for U.S. and global welfare (Dasgupta and David 1994).

One of the few attempts at a rigorous assessment of the effects of the Bayh-Dole Act on university research is the work of Henderson, Jaffe and Trajtenberg (1995, 1998a, 1998b), which examined the impact of Bayh-Dole on the "quality" of university patents, as measured by the number of times these patents are cited by subsequent patents. The authors found that this measure revealed a decline in the quality of academic patents after Bayh-Dole. In this paper, we show that the post-Bayh-Dole "quality decline" identified by Henderson and colleagues disappears in analyses that employ patent-citation data covering a longer time period than the data used by these scholars. We find that the "quality decline" that Henderson et al. identified in their analysis reflects changes in the intertemporal distribution of citations to university patents, rather than a significant change in the total number of citations these patents eventually receive. Our analysis suggests that during the post-Bayh-Dole period, the lag between application and issue dates for university patents has increased, and citations to university patents occur somewhat later, on average, after issue. These changes may themselves reflect significant differences since 1980 in the content and contributions of university research to innovation.

2. Patent Citations, and the post-Bayh-Dole "Quality Decline"

Henderson and colleagues (1995, 1998a, 1998b) (hereafter, "HJT") used publicly available information contained in the front pages of patents assigned to universities during 1965-1988 and in subsequent patents that cited those university patents through the end of 1992

state (government) to the (public or private) agent performing the research. The underlying rationale for such change is that it increases the social rate of return on public investment in research" (OECD 2002, p. 48).

to examine changes in the characteristics of patents issued to U.S. universities before and after Bayh-Dole.

Patent-based measures have been utilized to measure innovative output for several decades (Griliches 1990). The large variance in the economic and technological significance of individual patents, however, means that simple patent counts are noisy indicators of innovative output. But weighting patents by the number of times they are cited in subsequent patents yields a better measure of the technological importance of these patents (See Trajtenberg 1990 for one of the first applications of this measure). Citations to one patent by many subsequent patents suggests either that numerous inventions draw on the knowledge embodied in that patent, and/or that this antecedent patent has opened up a significant new field of inventive activity, within which follow-on patents must carefully differentiate their contribution from the prior art represented by this patent and others. Scholars have also used citation-weighted patent counts as measures of the private value of an invention to the patentholder (Hall et al. 2000, Shane and Klock 1997, Austin 1994, Harhoff et al. 1999, Sampat and Ziedonis 2002), and still other empirical work has shown that more heavily cited patents are more likely to be the subject of litigation, another measure of their economic value (Lanjouw and Schankerman 2000).

The work of HJT concluded that expanded patenting by U.S. universities after Bayh-Dole was accompanied by a decline in the quality of these patents, as measured by citations. According to HJT, university patents issued before the passage of the Bayh-Dole Act were significantly more likely to be cited than a 1% random sample of all U.S. patents. But for university patents issued after 1980, this difference diminished and its statistical significance disappeared completely for university patents issued after the mid-1980s.

The meaning of this relative decline in citations to U.S. university patents is open to multiple interpretations. Some authors have interpreted this finding as evidence that research priorities within universities may have shifted towards "applied research" after Bayh-Dole (e.g. Foray and Kazancigil 1999).[3] Implicit in this interpretation is the assumption that patents based on "basic" research would generate a higher level of citations than "applied" research (cf. Trajtenberg et al. 1997). Alternatively, of course, one could argue that more applied university research should generate more heavily cited patents, based on the utility of these patents for industrial innovation.[4] The different interpretations that can be placed on patent-citation counts underscores the complexities of their economic interpretation.

Although HJT's results attracted considerable attention, further analysis is merited for at least two reasons. First, their analysis relies on citations to university patents only through 1992, although patents in their sample were cited well after 1992. The lack of observations on citations after 1992 thus could introduce a "truncation bias," reflecting the fact that earlier patents (those issued further in advance of 1992) enjoy a longer period of potential citation than later patents. Although HJT control for some sources truncation bias, their analysis reveals the most substantial "quality decline" for the most recent patents in their sample, those for which truncation bias may be most significant. Thus, the nature of their data and results suggest that further analysis employing a longer period for post-issue citations is worthwhile. Second, several recent papers (Mowery and Ziedonis 2001, Mowery, Sampat, and Ziedonis 2002) find no

[3] Henderson and colleagues also suggested this possible interpretation of the "quality decline" in an early version of their paper, Henderson et al. (1995).

[4] HJT (1998a,b) appear to interpret citations in this way, arguing that their results suggest that "… the Bayh-Dole Act and 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 towards areas likely to produce commercial inventions, or, if they did, they did so unsuccessfully" (Henderson et al. 1998b, p. 126).

decline in citation-based measures of academic patent quality after 1980, although these analyses employ different control samples and methodologies.

3. The "Quality Decline" Revisited

Our analysis utilizes a longer time series of citations to university and industrial patents to further analyze the quality decline reported in Henderson et al. (1998), but in all other respects is essentially identical to that of HJT. Our dataset consists of all university patents applied for between 1975 and 1988 and granted before 1992, identical to that used by HJT.[5] We also followed HJT in constructing a 1% random sample of all U.S. patents granted during the same period. Although we do not have access to the identical control sample used by HJT, we believe that this control sample is sufficiently similar to theirs for the purposes of this analysis.[6] We collected counts of all citations to the university patents and control sample patents that appeared by the end of 1999, adding seven years to the citation time series employed in HJT.[7]

3.1 Basic Analysis

For purposes of comparison, we create two citation counts for each potentially cited patent, (1) the number of citations generated by the patent through the end of 1992, which covers the period included in the HJT analysis, and (2) the number of citations generated by the patent through 1999. Since we are interested in the overall "importance" of a patent, we follow HJT in including self-citations in these counts, but our main conclusions are not sensitive to the inclusion or exclusion of self-citations.

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[5] Rebecca Henderson kindly provided us with access to the list of university patents used in their analyses.
[6] We checked the sensitivity of our basic results to the use of any particular control sample employed by conducting the analysis discussed below using 5 different 1% control samples. The results of these analyses are virtually the same as those reported, and are available from the authors upon request.
[7] These data were taken from the Case Western Reserve - NBER Patent Citation database, described in Hall et al. (2001).

Table 1 reports descriptive statistics for patent citation counts in the overall sample of patents, the university patent sample, and the control sample. Increasing the observation period for citations from 1992 to 1999 increased the mean number of citations for patents in all three samples. Regardless of the time-span of citation data collected, university patents are more highly cited than the control patents (4.153 vs. 3.494 using citations as of 1992, and 10.605 vs. 7.047 using citations as of 1999).

*** Table 1 Here ***

Our regressions employ the number of citations to the sample patents as the dependent variable, similarly to HJT. The independent variables include dummy variables for application year, patent class dummies for each of the patent classes included in the university and control patent samples, and application year dummies interacted with a dummy variable indicating whether the patent is a university or control sample patent.[8] More formally, we estimate equations of the form:

$$CITES_i = \sum_t \left[\alpha_t APP_t + \beta_t (APP_t * UNIV)\right] + \sum_c \lambda_c CLASS_c + \varepsilon_i \qquad (1)$$

where $CITES_i$ is the number of citations to patent *i*, APP_t is a dummy variable taking on the value of 1 if patent was applied for in year *t* (*t* = 1975, … ,1988), UNIV is a dummy variable taking on the value of 1 if patent *i* is in our university sample, $CLASS_c$ is dummy variable taking on the value of 1 if the patent class is *c*, and ε_i is the error term.[9] The coefficients on the interaction terms, β_t, are estimates of the mean differences in the number of citations to university patents and patents from our random sample for a given application year, controlling

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[8] The sample analyzed by HJT begins in 1965. Unfortunately, it is difficult to obtain citation information for patents issued prior to 1975, and our sample therefore excludes those patents applied for before 1975. Since the observed "quality decline" occurs after the mid-1980s, this data limitation does not affect the substance or the conclusions of our analysis.

[9] Our university and control patents span 394 patent classes.

for technological field effects. Following HJT, we estimate this equation using ordinary least squares (OLS).

The main results are shown in Table 2, which displays the estimated interaction-term coefficients. The first column of the table presents the coefficient estimates from Table 4 of Henderson et al. (1998b). The second column displays the coefficients that we obtained from estimating the specification described in the previous paragraph for patent-citations data through 1992. The magnitude, sign, and statistical significance of the coefficients that we obtain (column 2) are very similar to those from HJT's 1998 article (column 1). The results in both columns 1 and 2 indicate that the citation-weighted "quality" of university patents relative to the controls declined after Bayh-Dole; the difference in citations to these two groups of patents is statistically insignificant for patents issued after the mid-1980s. University patents are actually cited less frequently than those in the control sample for patents applied for in 1987 and 1988, although this difference in citation intensity is not statistically significant.

*** Table 2 Here ***

Column 3 of Table 2 presents results from estimating the specification described above with patent citation data that extend through 1999. The results change dramatically--university patents are more highly cited than the controls for patents applied for after as well as before Bayh-Dole, and the difference is statistically significant for all years.[10] Re-estimation of the original HJT specification with a longer time series of citations yields little evidence of a post-Bayh-Dole "quality decline" in U.S. university patents, something that is illustrated graphically

[10] At the suggestion of a reviewer, we estimated the quality differences using negative binomial regressions, since the dependent variable (citations) is integer-valued. The results are similar to those obtained via OLS, and are available from the authors upon request.

in Figure 1, which plots the coefficients on the interaction term from both regressions, along with the coefficients from HJT's analysis.[11]

*** Figure 1 Here ***

To further test for the possibility of a significant difference between pre- and post-Bayh-Dole academic patents, we regressed citations on a pre-Bayh-Dole and post-Bayh-Dole dummy, each interacted with a university dummy, as well as application year and patent class dummies. When using "citations through 1992" as the dependent variable, the estimated coefficient on the pre-Bayh-Dole-University interaction term dummy is 1.8 and the estimated coefficient on the post-Bayh-Dole-University interaction term dummy is 0.55. An F-test of equality of coefficients rejects the hypothesis that the coefficients are equal. When we use "citations through 1999" as the dependent variable, however, the estimated pre- and post-Bayh-Dole coefficients are 3.2 and 2.8 respectively, and we cannot reject the hypothesis that they are equal. In other words, the analysis of patent citations through 1999 yields no evidence of a significant change in the quality of university patents relative to the controls after Bayh-Dole.[12]

Based on these results, we conclude that the original HJT findings are sensitive to the number of years of citation data used. The HJT analysis included only 4 - 7 years of citation data for the patents applied for by universities during 1985-1988, but our longer time series includes 11 - 14 years of citations for these patents. In other words, the patent "quality decline"

[11] Henderson et al. also found that the "generality" of university patents--a measure of the dispersion of citations across technological fields--declined relative to the controls the after the passage of Bayh-Dole. In addition to the results reported above, we calculated generality for the university and control sample patents using citations observed through 1999, and found no evidence of a decline in the generality of university patents. These results are available from the authors upon request.

[12] In conducting this test of the equality of the coefficients, we are testing the hypothesis that a "breakpoint" occurs in 1980, the year of passage of the Bayh-Dole Act. A less restrictive test of the structural stability of these coefficients that does not require imposing a specific breakpoint is the residual-based Brown-Durbin-Evans (BDE) test (Link, Paton, and Siegel 2002).

reported by HJT appears to be an artifact of truncation bias.[13] In Section 4, we discuss the nature and effects of truncation in more detail.

4. Truncation Bias

The use of a shorter time span of citations could create the impression of a decline in the quality of university patents in at least three ways. First, consider the case in which university patents are more highly cited than the controls across the entire life of the patent and the intertemporal distribution of citations is identical, i.e., at any point in time the same proportion of total citations is observed for patents from each sample. In this case, a shorter "window" of observations of citations to the two patent samples would produce a smaller cumulative difference in citations. Secondly, the intertemporal distribution of citations could differ for the university and control sample patents, with citations to university patents occurring later (on average) than the controls. In this case, a relatively short "window" of observations for both sets of patents could understate differences in citation-intensity for university and control patents, and this form of truncation bias again would be greater for relatively recent patents. A third possibility is that the intertemporal distribution of citations is changing over time, i.e. citations to

[13] It is well known that patent values, like most measures of innovative output, are highly skewed--patents in the upper tail of the patent value distribution account for the bulk of the value of patent portfolio (Harhoff and Scherer 1999). HJT suggest that their "quality decline" could reflect increased patenting of "marginal" inventions by universities after Bayh-Dole, in response to a reduction in the costs of patenting. In this view, Bayh-Dole led U.S. universities to reduce the threshold level of invention quality above which they would file for patent protection. Despite our finding that the "quality decline" disappears with the addition of additional years of citation data, their threshold hypothesis may still be valid. Because they estimate conditional means, our least-squares regressions are unable to test this hypothesis. We therefore also estimated quantile regressions (which estimate conditional quantiles) to explore changes in "quality" over time between patents within different quantiles, in order to examine effects of Bayh-Dole on the entire distribution of citations. We estimate these regressions for q = 0.1, 0.25, 0.5, 0.75, and 0.9. The results (not reported) show no evidence of a post-Bayh-Dole decrease in the quality of university patents (relative to the controls) in any of the quantiles. Indeed, there is some evidence in these results of an *increase* in quality in the upper quantiles of our university patent sample. These results should be interpreted with caution, however, since in order to obtain convergence, we aggregated the 394 patent class dummies into five broad technological categories using the taxonomy created by Jaffe, Fogarty, and Banks (1999). These regressions thus do not include complete controls for differences in citation intensity across patent classes.

university patents are arriving later (relative to citations to the control sample patents) in more recent application years. Since HJT control for the first two forms of potential truncation bias in their analysis, the third may explain the different results that we obtain in using a longer "window" of observations of citations.

Evidence that citations to university patents occur later on average (relative to citations to patents in the control sample) in more recent application years is provided in Figures 2-4, which display plots of the cumulative distribution of citations received in 11-year "windows" following the date of application for university and control patents applied for respectively during three periods: 1977-1980, 1981-1984, and 1985-1988. The value of the cumulative distribution function at $t = x$ years after the patent application ($0 \leq x \leq 11$) is the proportion of total citations during the 11-year period that are observed after x years. Use of an 11-year window enables us to examine the same "span" of citations for all patents and identify shifts in the intertemporal distribution of citations within that span.

As we noted earlier, the data analyzed by HJT captured only four years of citation for the most recently issued patents in their sample, those applied for in 1988 by universities or corporations. The data in Figure 2 indicate that the 1977-1980 cohort of patents in our control sample accumulate 16.3% of their "total" citations (i.e., citations accumulated within 11 years of the application date) during the first four years following their application date. The identical cohort of university patents, however, accumulate 12.6% of their "total" citations during the first four years following their application date. For patents with application dates in the 1981-1984 period, however, these respective proportions are 15.1% and 9.4% respectively (Figure 3), and in Figure 4, covering 1985-88, these proportions are 18.7% and 12.0% respectively. A visual comparison of the three figures suggests that the differences between the portion of citations received by university and control sample patents are greater in more recent patent cohorts for several years after $t = 4$ years. That is, citations to university patents in the 1981-84 and 1985-88 cohorts occur later than citations to patents in the control sample by a growing margin.

*** Figures 2 - 4 Here ***

The data in Figures 2 - 4 do not consider differences among technological fields. We therefore estimate two models to analyze changes in the distribution of citation lags for university and control-sample patents that control for patent class. First, we calculate the average lag for forward citations for each cited patent using all citations within 11 years of the application date, and estimate the following equation:[14]

$$Average\ \ Citation\ \ Lag_i = \sum_t \left[\alpha_t APP_t + \beta_t (APP_t * UNIV) \right] + \sum_c \lambda_c CLASS_c + \varepsilon_i \qquad (2)$$

where the dependent variable is the average lag for all citations to patent i within the 11 year window. We also estimate a similar equation that uses median citation lags as the dependent variable:

$$Median\ \ Citation\ \ Lag_i = \sum_t \left[\alpha_t APP_t + \beta_t (APP_t * UNIV) \right] + \sum_c \lambda_c CLASS_c + \varepsilon_i \qquad (3)$$

The least squares estimates of the differences in average and median citation lags (the β coefficients) are shown in Table 3. In 8 of the 9 years before 1984, there are no significant differences between the university and controls in the (average or median) lengths of lags to "forward" citations. In each year after 1984, both the mean and median forward lags are significantly longer for the university patents.

*** Table 3 Here ***

14 The lags in Figures 2 - 4 were calculated across each citing-cited pair, but the "average" and "median" lags used in these regressions are calculated at the level of the cited patent.

These results indicate that citations to university patents are indeed arriving later relative to citations to the control-sample patents in the 1980s, controlling for technology class, i.e. there is a systematic change in the intertemporal distribution of citations to university patents during the 1980s.

One possible source of this shift is a change in the application-grant lags, or "pendency" of patents in the university and control samples. In both the HJT analysis and ours, university patents are dated by application year. But since U.S. patent applications historically have not been open to the public, the "citation clock" for parties other than the patent examiner to cite a patent begins only after the patent is issued.[15] Any systematic tendency for the pendency lags for university patents to grow relative to those for patents in the control sample during the 1980s could produce an apparent shift in the intertemporal distribution of forward citations to university patents similar to that observed in our data.

To examine whether application-grant lags changed between the 1970s and 1980s, we regressed "pendency lags" on application-year dummies, a university dummy interacted with application-year dummies, and patent class dummies, estimating the following equation:

$$APPLAG_i = \sum_t \left[\alpha_t APP_t + \beta_t (APP_t * UNIV)\right] + \sum_c \lambda_c CLASS_c + \varepsilon_i \qquad (4)$$

The coefficients on the interaction terms (β_t) are shown in Table 4 and are plotted in Figure 5. Before 1983, in all application years but one, the differences between the application-grant lags for the university and control sample patents are not statistically significant. But in each application year during 1983-1988, the lags are significantly longer for university patents than for the controls, and this difference appears to be increasing over time (Figure 5).

[15] Beginning in November 2000, most U.S. patent applications are published 18 months after the filing of the earliest related application.

*** Table 4 Here ***

*** Figure 5 Here ***

Thus university patents take longer to be granted, relative to the controls, for applications filed after 1982. To examine whether this change in average pendency is responsible for the shift in the intertemporal distribution of citations, we re-estimated our average and median citation lag regressions with controls for the application-grant lag of the cited patents. Figures 6 and 7 plot the estimated coefficients for the interaction terms in these specifications, which capture the mean differences in average and median citation lags for university and control sample patents. The results indicate that after controlling for application-grant lags, the magnitude of the (relative) increase in citation lags decreases but does not vanish. Intertemporal changes in application-grant lags thus provide part of the explanation for the observed changes during the 1980s in the intertemporal distribution of citations. Nevertheless, the changing citation lags reflect more than just longer pendency lags for university patent applications during the 1980s.

Why do university patents take longer to be granted during the 1980s, relative to our control patents? A thorough explanation for this phenomenon is beyond the scope of this paper, although it raises interesting issues for future research. Our analysis does highlight the sensitivity of citation-based analyses of patent characteristics to the techniques used to "date" the patents. Since the actual date of the invention underlying a patent application necessarily is closer to the application than to the issue date of the patent, the application date is preferable for analyses of the timing of inventive behavior. But the variation in pendency lags noted above provides one argument for employing issue dates in some analyses of patent citations. The ultimate choice of date will depend on the purposes of the analysis. Using issue dates removes one source of intertemporal changes in the distribution of forward citations.

Nevertheless, Figures 6 and 7 show that even after controlling for changes in application-grant lags, citations to university patents occur later than those to the controls after the mid-1980s. The interpretation of such changes in the intertemporal distribution of citations, however, depends on the meaning of early versus late citations, the topic of several recent empirical studies.

Lanjouw and Schankerman (1999) found that early citations (those observed within 5 years of application date) were highly correlated with their measures of the importance and economic value of patents taken from the application (i.e., number of claims, number of backward citations, number of countries in which patent protection is sought). Later citations were less highly correlated with these measures of patent quality that are based on characteristics of the patent at its issue date. Lanjouw and Schankerman suggest that their finding could indicate that later citations to a patent have a weak relationship to the economic value of the cited patent, perhaps because such citations are simply "citing the classics." Alternatively, of course, later citations may be valid measures of patent quality that are uncorrelated with the Lanjouw-Schankerman "time-zero" measures of patent quality. This interpretation receives some support in the results of Hall, Jaffe, and Trajtenberg (2000), who find that unanticipated future citations (those not predicted by early citations) are the most important correlates of the market value of the firm that is the assignee of the patent.

If later citations to patents are poor indicators of the value or "quality" of these patents, then the shifts that we observe in the intertemporal distribution of citations to university patents could indicate some decline in the "quality" of these patents after Bayh-Dole. But if later citations are in fact more accurate measures of the "quality" of these patents, our results are consistent with an improvement, rather than a decline, in university patent quality.

Still other scholars have interpreted patent citations as (noisy) measures of knowledge "spillovers," and a finding that university patents are systematically being cited later suggests that patent-embodied knowledge flows from universities are incorporated into future patents more slowly in the wake of Bayh-Dole. If "science-based" patents take longer to be cited in subsequent patents, then this longer lag in the citation of university patents might reflect some tendency for U.S. universities to patent "science" rather than technology in the aftermath of Bayh-Dole.[16] Alternatively, it is possible that the nonpatent "knowledge complements" resulting from university research (e.g., publications or conference presentations) are being disseminated more slowly as a result of a greater institutional emphasis on patenting and secrecy in the disclosure of research results before patent applications are filed. Any constriction in the supply of these complementary academic inputs into industrial patenting could slow the rate of exploitation by industrial inventors of academic knowledge, be this patented or unpatented. Either of these possibilities raises serious issues for societal welfare, since they suggest that the "scientific commons" that underpins the advance of knowledge has been eroded (see Eisenberg and Heller 1998, Eisenberg and Nelson 2001).

5. Conclusion

Our analysis of citations to university patents before and after the Bayh-Dole Act suggests that there is no decline in the "quality" of university patents during the 1980s. The quality decline

[16] Examining university patents granted over the 1975-1996 period and a 1% matched control sample, Sampat (2002) found that the number and share of citations in these patents to non-patent prior art increased dramatically beginning in the late 1980s, which may indicate that universities were patenting more "scientific" than "technological" research results.

observed by HJT reflects truncation of the citations data as well as some change in the intertemporal distribution of citations to university patents. These findings are consistent with earlier results (Mowery and Ziedonis 2001; Mowery, Sampat, and Ziedonis 2002) that also used longer citation-data time series than were available to HJT.[17] The sensitivity of these results to truncation and the difficulties in controlling for truncation in the face of shifts in citation lags also highlight the sensitivity of patent-citations analyses to the construction of the relevant datasets.

Finally, the most important questions relating to the effects of the Bayh-Dole Act on U.S. university research and technology transfer cannot be answered solely with patent citation data. Has Bayh-Dole affected the incentives of academic researchers? Does the introduction of commercial incentives into university research threaten the norms of academe? Have universities begun to patent and license "science" that they previously disseminated freely? Are patents on academic research outputs necessary to facilitate technology transfer? These are important questions that cannot be addressed with patent and patent citation data alone. In addition to paving the ground for subsequent work using patent citation data, another "spillover" from the paper by Henderson and colleagues is that it has focused attention and stimulated research on the broader issues relating to the effects of Bayh-Dole, an important contribution indeed.

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[17] Mowery, Sampat, and Ziedonis (2002) use only citations observed within 5 years of the issue date of patents, although a median application-grant lag of 2 years that yields approximately seven years of citation data may be sufficient. The Mowery et al. analysis also uses a different control sample from HJT and excludes self-citations, another feature that may contribute to these differences in results.

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Table 1: Descriptive Statistics for Patent Citation Counts

Statistic	Mean	Standard Deviation	Minimum	Maximum
Overall Sample, N = 17,996				
Number of Patent Citations as of 1992	3.798	5.625	0	126
Number of Patent Citations as of 1999	8.609	12.038	0	292
University Sample, N = 8,304				
Number of Patent Citations as of 1992	4.153	6.549	0	126
Number of Patent Citations as of 1999	10.605	14.442	0	292
Control Sample, N = 9,692				
Number of Patent Citations as of 1992	3.494	4.669	0	81
Number of Patent Citations as of 1999	7.047	9.195	0	166

Table 2: Mean Difference in Number of Patent Citations, University vs. Control Samples

	Dependent Variable:		
	1	2	3
Patent Application Year	Number of Patent Citations as of 1992 HJT 1998 (Table 4)	Number of Patent Citations as of 1992	Number of Patent Citations as of 1999
1975	2.54 *** (0.35)	2.48 *** (0.35)	3.21 *** (0.77)
1976	1.82 *** (0.34)	1.67 *** (0.35)	2.20 *** (0.76)
1977	1.31 *** (0.34)	1.42 *** (0.35)	3.02 *** (0.77)
1978	2.04 *** (0.34)	2.33 *** (0.34)	4.50 *** (0.75)
1979	1.13 ** (0.31)	1.34 *** (0.32)	2.41 *** (0.71)
1980	1.91 *** (0.31)	1.82 *** (0.31)	4.01 *** (0.67)
1981	1.68 *** (0.31)	1.93 *** (0.32)	3.98 *** (0.69)
1982	0.96 *** (0.31)	1.49 *** (0.31)	3.87 *** (0.68)
1983	0.97 *** (0.30)	1.14 *** (0.31)	2.89 *** (0.67)
1984	0.47 * (0.28)	0.36 (0.29)	2.22 *** (0.64)
1985	0.40 (0.28)	0.68 ** (0.28)	3.41 *** (0.62)
1986	0.06 (0.27)	0.06 (0.27)	2.98 *** (0.60)
1987	-0.07 (0.25)	-0.11 (0.25)	1.90 *** (0.56)
1988	-0.08 (0.24)	-0.16 (0.24)	1.89 *** (0.53)
Year Dummies	Significant	Significant	Significant
Patent Class Dummies	Significant	Significant	Significant
Number of Obs.	NA	17,996	17,996

Notes:
*** p<0.01 ** p<0.05 * p<0.10
Standard errors in parentheses.

Table 3: Mean Difference in Average and Median Patent Citation Lags, University vs. Control Samples

	Dependent Variable:	
	1	2
Patent Application Year	Average Forward Citation Lag	Median Forward Citation Lag
1975	-0.093 (0.13)	-0.127 (0.15)
1976	-0.038 (0.13)	-0.067 (0.15)
1977	0.336 ** (0.13)	0.295 ** (0.15)
1978	0.123 (0.12)	0.187 (0.14)
1979	-0.113 (0.12)	-0.135 (0.13)
1980	0.086 (0.11)	0.073 (0.13)
1981	0.152 (0.11)	0.183 (0.13)
1982	0.177 (0.11)	0.156 (0.13)
1983	0.068 (0.11)	0.073 (0.12)
1984	0.221 ** (0.10)	0.239 ** (0.12)
1985	0.344 *** (0.10)	0.337 *** (0.11)
1986	0.502 *** (0.10)	0.501 *** (0.11)
1987	0.419 *** (0.09)	0.481 *** (0.10)
1988	0.366 *** (0.09)	0.395 *** (0.10)
Year Dummies	Significant	Significant
Patent Class Dummies	Significant	Significant
Number of Obs.	15,299	15,299

Notes:
*** p<0.01 ** p<0.05 * p<0.10
Standard errors in parentheses.

Table 4: Mean Difference in Application-Grant (Pendency) Lags, University-Control Sample

Patent Application Year	Dependent Variable: Application-Grant Lag
1975	0.110 * (.064)
1976	0.087 (.063)
1977	0.123 * (.064)
1978	0.022 (.062)
1979	0.121 ** (.059)
1980	0.100 * (.056)
1981	0.058 (.058)
1982	0.074 (.057)
1983	0.195 *** (.056)
1984	0.353 *** (.053)
1985	0.299 *** (.051)
1986	0.349 *** (.050)
1987	0.304 *** (.046)
1988	0.184 *** (.045)
Year Dummies	Significant
Patent Class Dummies	Significant
Number of Obs.	17,996

Notes:
*** $p<0.01$ ** $p<0.05$ * $p<0.10$
Standard errors in parentheses.

Figure One: Coefficients on University*Application Year Interaction Term, By Application Year

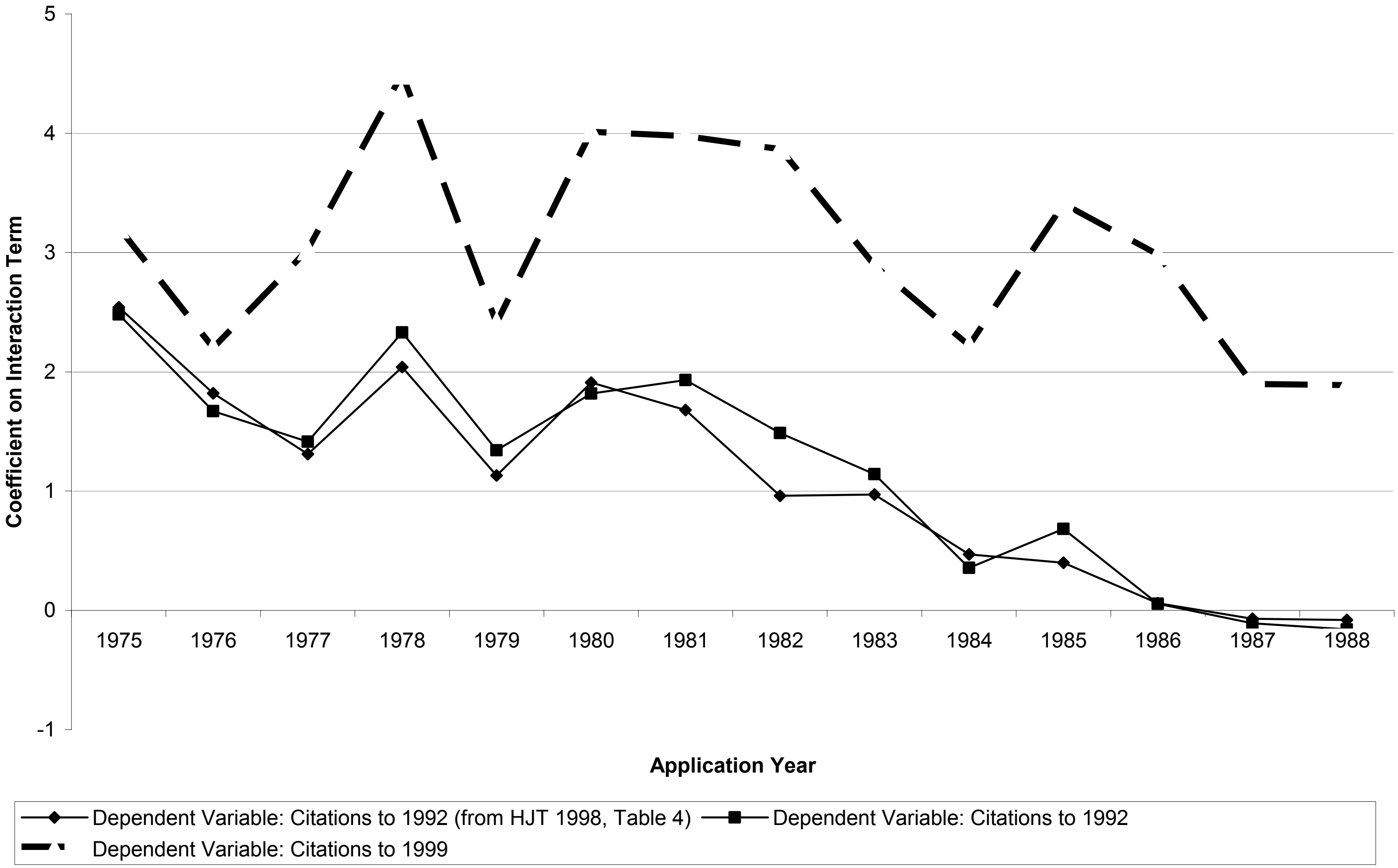

Figure 2: Cumulative Distribution of Citation Lags, University and Control Patents, 1977-1980

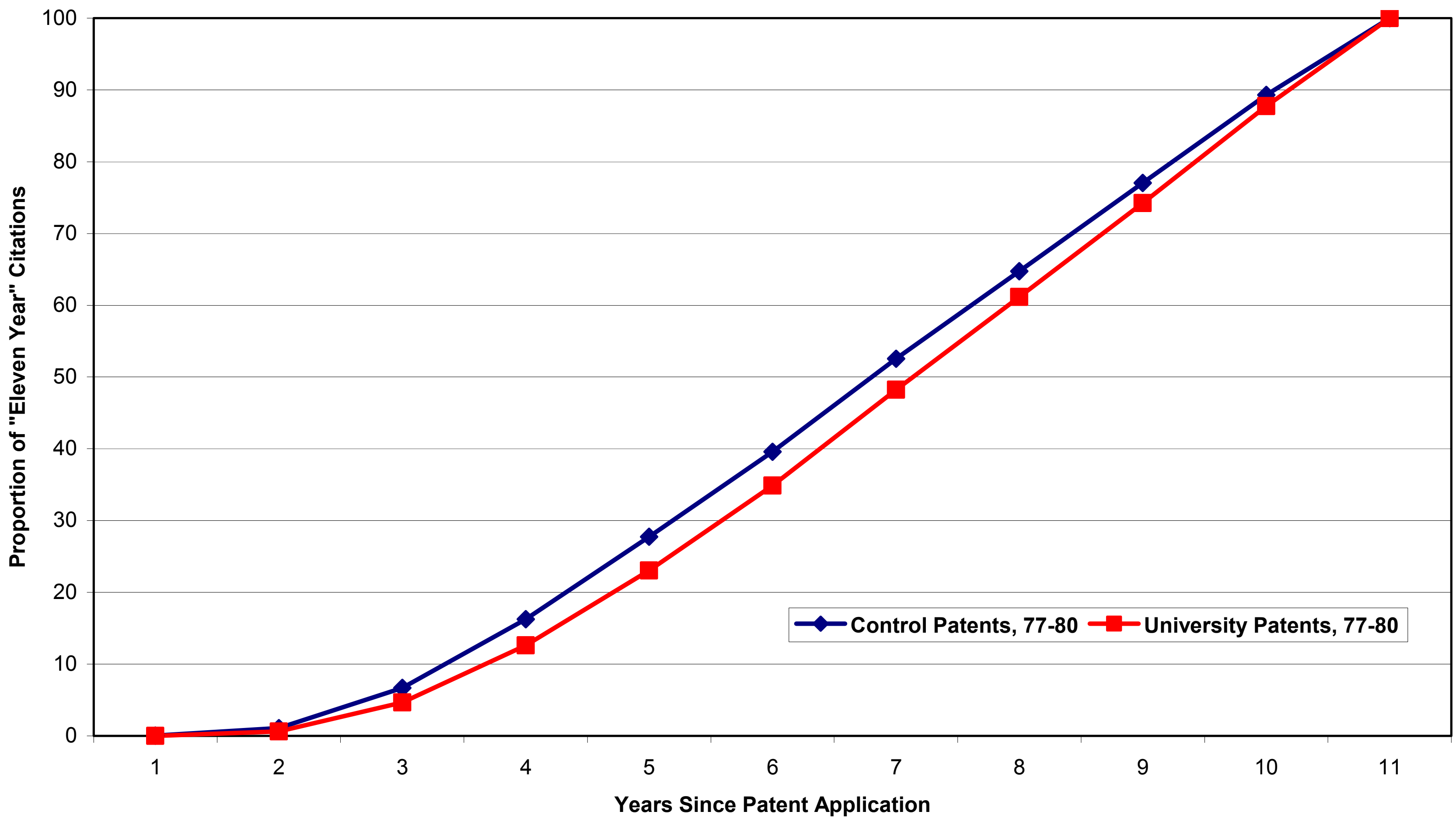

Figure 3: Cumulative Distribution of Citation Lags, University and Control Patents, 1981-1984

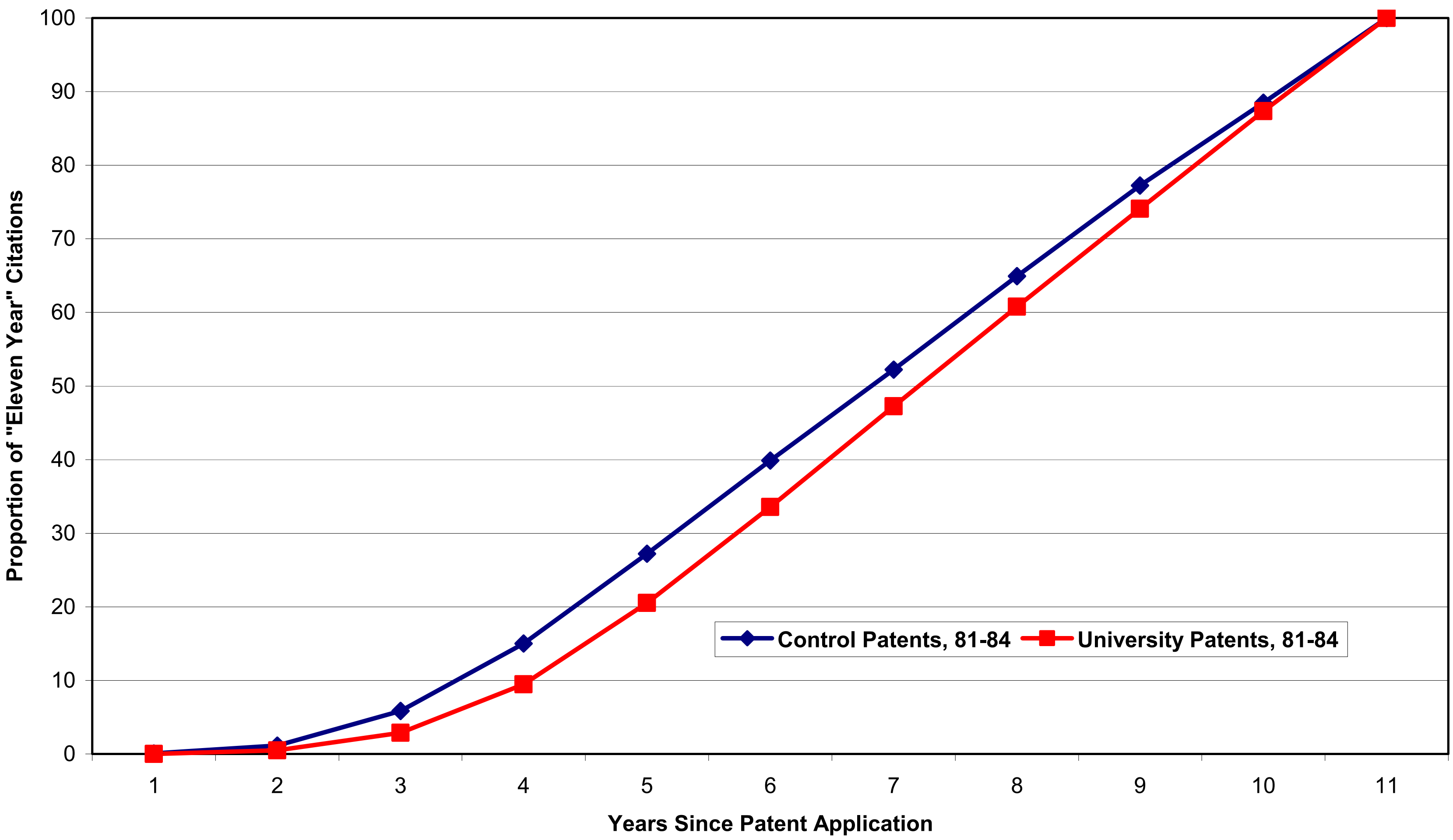

Figure 4: Cumulative Distribution of Citation Lags, University and Control Patents, 1985-1988

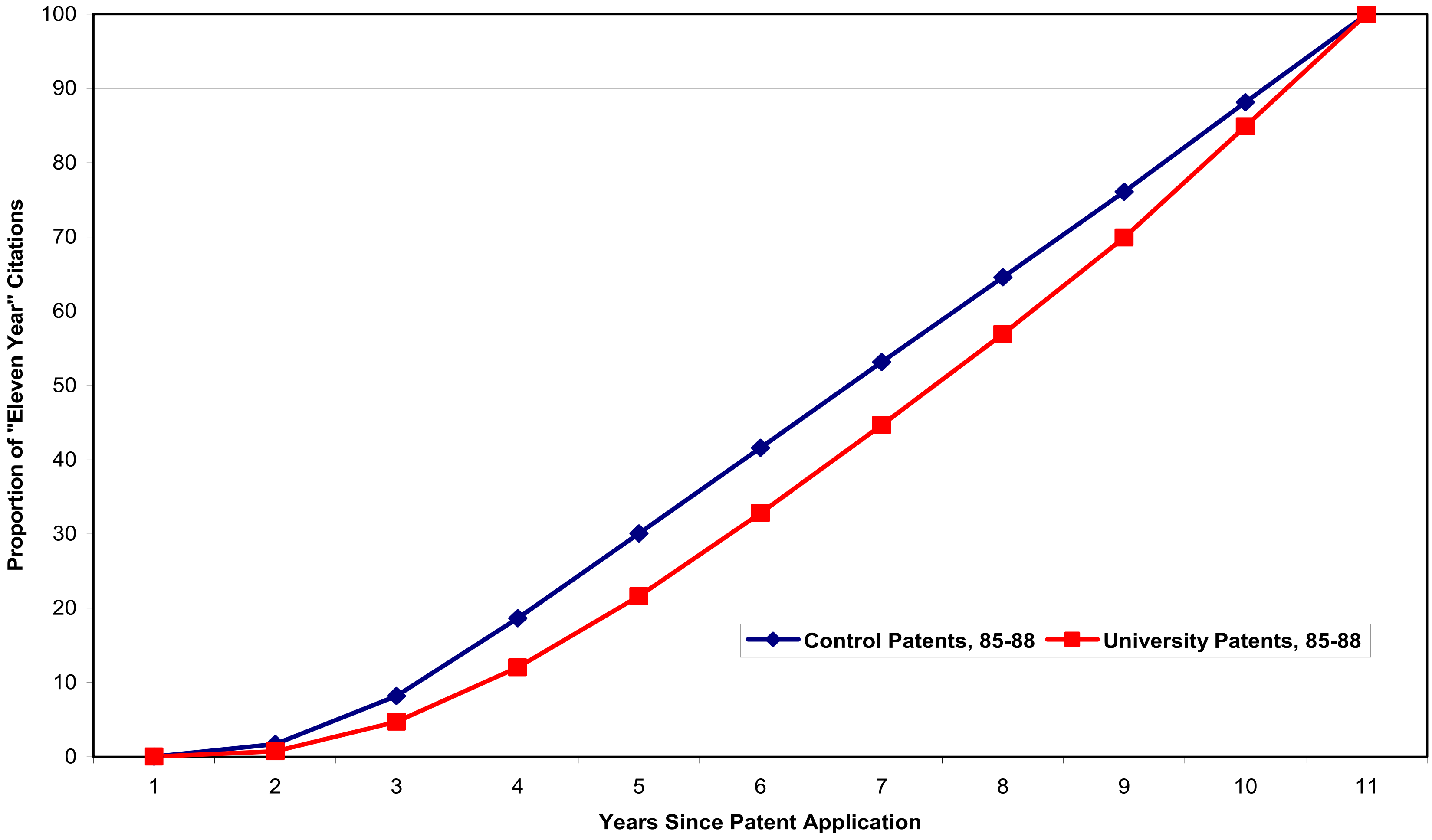

Figure 5: Mean Difference Between Pendency Lags for University/Control Samples

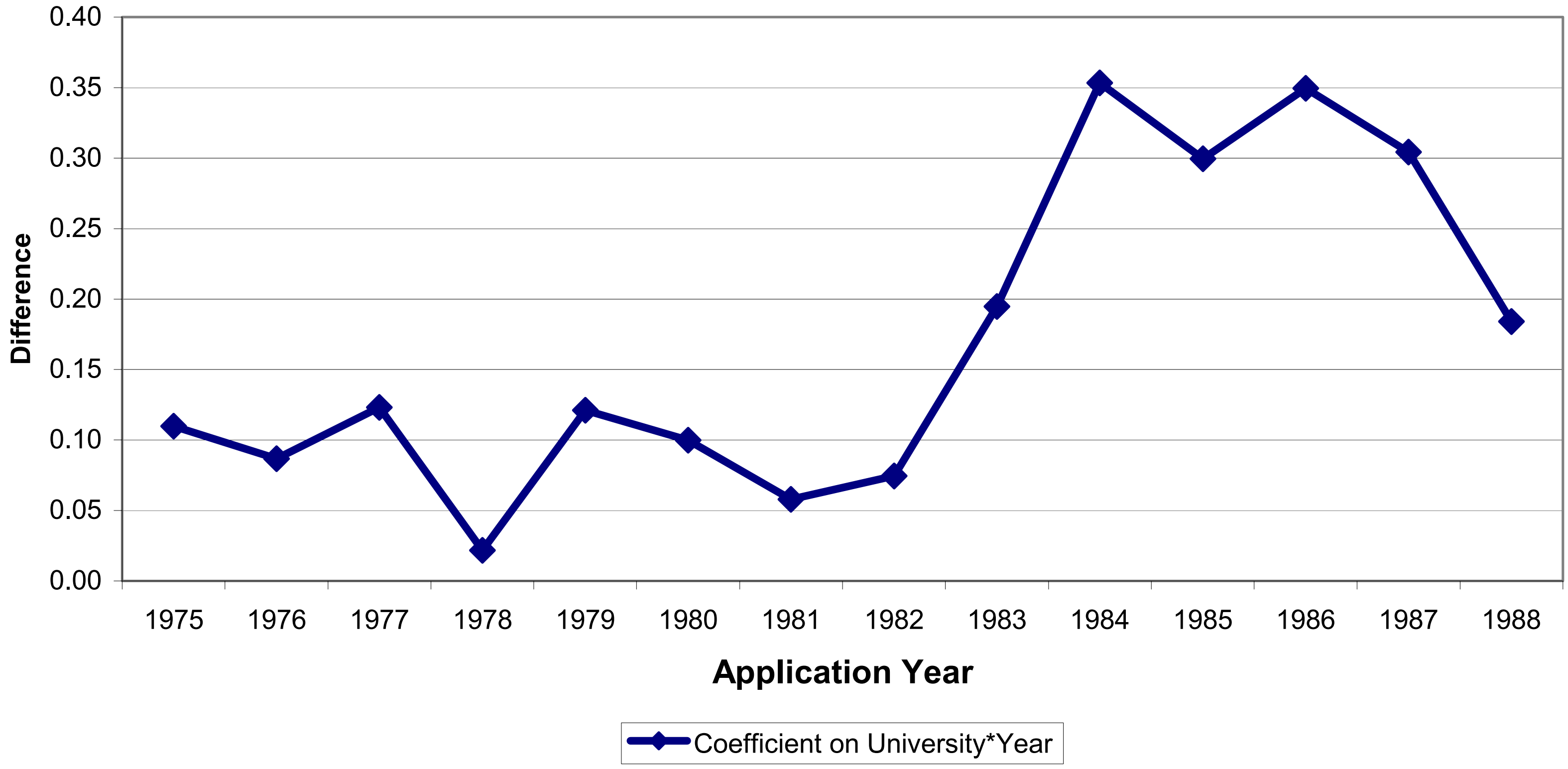

Figure 6: Difference in Average Citation Lags (University-Controls) by Application Year

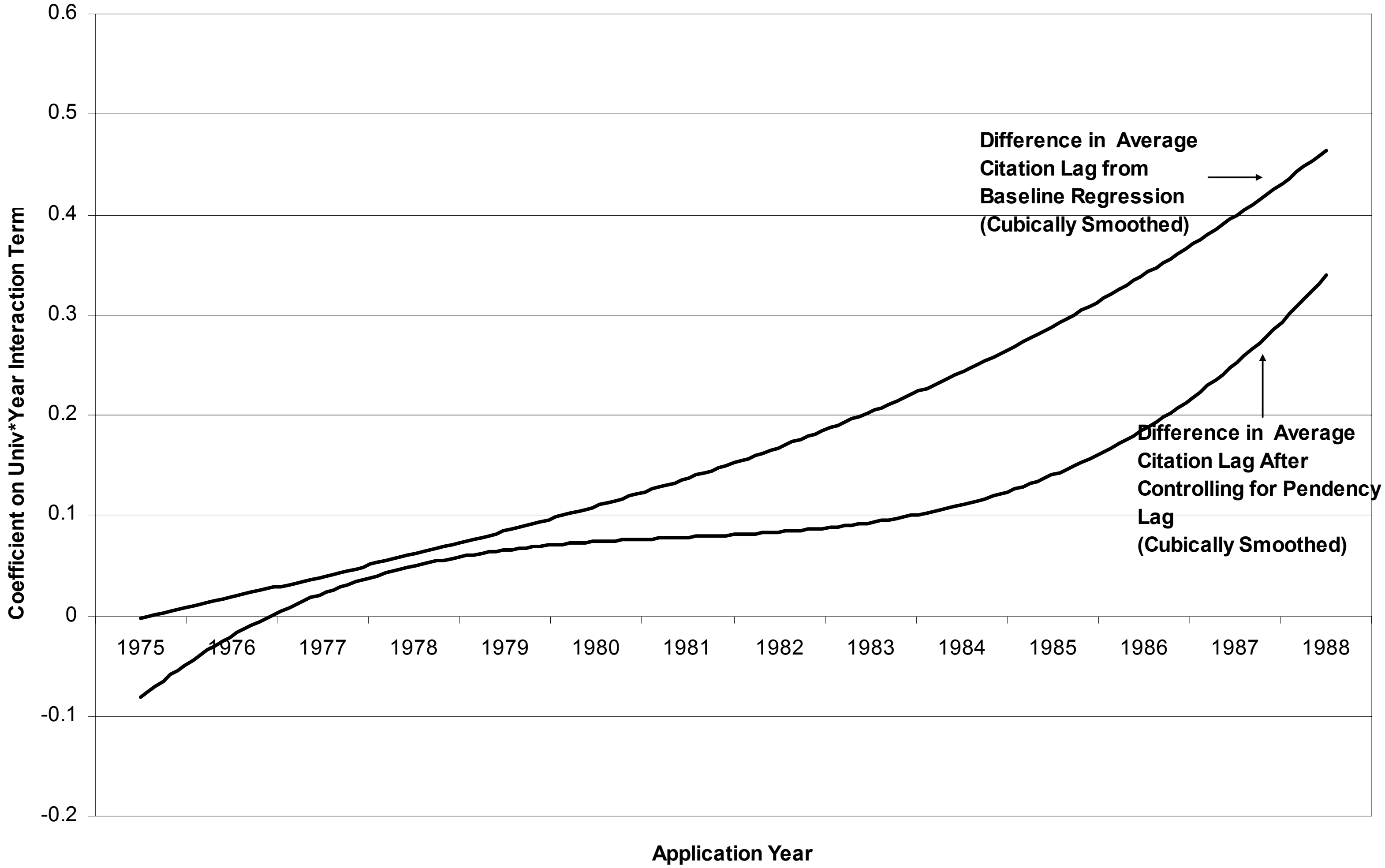

Figure 7: Difference in Median Citation Lags (University-Control) by Application Year