California's Inventive Activity: Patent Indicators of Quantity, Quality and Organizational Origins

A Report Prepared for

The California Council on Science and Technology

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October 11, 1999

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CCST's California Report on the Environment for Science and Technology (CREST) has analyzed the state's science and technology infrastructure to determine if California has the people, capital investment and necessary state governmental policies to maintain California's leadership in the face of increasing worldwide competition. Through eight individual research projects, CREST analyzes the state's ability to create and use new technology. By facilitating a dialog with policy makers, industry leaders, and academic communities, CCST hopes to enhance economic growth and quality of life for Californians.

Acknowledgments

The California Council on Science and Technology gratefully acknowledges support from the W. M. Keck Foundation of Los Angeles, CCST's Sustaining Members, and the State of California.

The authors are indebted to two talented research assistants Xiaogang Wu and Marc Junkunc. Special thanks go to James Zheng, HZ Multimedia, and to David Waguespack, postdoctoral fellow on the authors' research team at UCLA, for updating the patent data. The authors wish to thank the California Council on Science and Technology for direct support of production of this report. The following organizations also provided significant support for the authors' patent work: the University of California Systemwide Biotechnology Research and Education Program, the University of California President's Office Industry-University Cooperative Research Program, and the National Bureau of Economic Research for research support that provided access to data on patents and high-technology classifications.

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 Library of Congress Cataloging Number in Publications Data Main Entry Under Title:

California's Inventive Activity: Patent Indicators of Quantity, Quality and Organizational Origins

ISBN 1-930117-10-8

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1. Introduction

How much inventive activity is occurring in California, compared to other high-technology states? How can we assess the quality of the inventive activity? And what are the changes in roles of universities and firms in supporting the work of individual inventors over time? To investigate these questions, we examine the number of patents granted, number of citations to these patents, and number of university and firm assignees listed on these patents from 1980 through 1996 or 1998, depending on data availability. We thus focus on the trends in patenting activity, patent quality, and the changing roles that businesses and universities play in patenting activity.

Patents are indicators of scientific and technological discovery, intellectual property rights, university, non-profit, and commercial research productivity, and (because there are costs associated with getting a patent granted) commercial potential of inventions. Patents are particularly interesting measures of inventive activity because patents lie at the nexus of the science/technology-economic exchange. If a scientific or technological invention has commercial potential, the probability that the invention will be patented increases. For high-technology firms, the number of patents granted and the quality of those patents are additional measures of success comparable to stock performance, products in development, and employment growth (Pakes 1985; Hall 1993, 1999; Darby, Liu, and Zucker 1999; Zucker and Darby 1998, 1999; Zucker, Darby, and Armstrong 1998).

However, patents are far from perfect indicators of invention, research productivity, or commercial potential because these three aspects can't be clearly separated from each other. Further, other factors, particularly the number of patent examiners, alters the numbers of patents issued independent of the actual underlying rate of invention or commercial potential of these inventions (Griliches 1990). One example is particularly relevant to the results we are reporting. A hiring freeze at the US Patent and Trademark Office was coupled with a 40% increase in workload from 1993 through 1998. This freeze created long delays in patent processing by USPTO until approximately 700 additional examiners were added in 1998, about a 25% increase in examiners. With more examiners_and a large backlog created by increasing numbers of patent applications—the rate of patents granted between 1997 and 1998 increased by 31.5 % (U.S. Patent and Trademark Office 1999a, b, and c).

Patents have both a universal and a local dimension. Inventions and discoveries codified and protected by patent are used throughout the U.S. and in foreign countries, but use tends to be concentrated in the nearby local area.[1] The local concentration often arises from the tacit character of newly created knowledge which is difficult to explain to others, inevitably embodied in the discoverers and those who actually do bench science with them. During this early period of knowledge development, the new invention is likely to be applied commercially near where it is discovered and often involves the top scientists or engineers who did the initial inventing. In some cases this involvement may be limited to consulting or part-time employment, while in other cases the top scientist or engineer may actually create a new firm within which the new discoveries will be commercialized.[2]

In this report, we primarily describe the frequency and quality of inventive activity and its movement toward commercialization occurring at the state level among thirteen high-technology states.[3] We also address the role that two types of organizations play in the invention and commercialization process: universities and firms.

2. Overview of California's Inventive Activity and Quality: Technical Considerations

To be a leader in science and technology, a state must have a strong base of inventive activity that is of high quality. To measure this, we rely on a very well-developed and complete data base of U.S. utility patents that has been jointly developed by leading researchers in the science and technology area and is proprietary to them, but available to us as Research Associates of the National Bureau of Economic Research (nauset, located at Case Western Reserve)[4] One of the most well developed

[1]See particularly, Jaffe (1989), Jaffe, Trajtenberg, and Henderson (1993), Edwin Mansfield (1995), Zucker, Darby, and Brewer (1998), and Darby and Zucker (1999).

[2]Zucker and Darby (1996b) and Zucker, Darby, and Armstrong (1998). The "star scientists" involvement appears to play a major role in determining which firms utilizing breakthrough discoveries will be most successful. Interestingly, these scientists often publish more and better science during the period they are involved with firms, apparently due to the greater resources which result from their commercial activities.

[3]For purposes of this study, high-tech states are defined as California, Connecticut, the DC-plex (DC, Maryland, Virginia), Illinois, Massachusetts, Michigan, New Jersey, New York, Ohio, Pennsylvania, Texas, Washington, and Wisconsin.

[4]We acknowledge the significant support for our work provided by the National Bureau of Economic Research (NBER) and by Adam Jaffe at Brandeis University and NBER who gave us access to the nauset data.

aspects of these data are the thorough geo-coding of the address of the first inventor on each utility patent granted by USPTO from over five years before the beginning of electronic records at USPTO through the end of 1996. We augment the patent time series by adding data from the US Patent and Trademark web site for 1997 and 1998.[5]

All utility patents have one or more inventors by definition, and these inventors are listed on the patent's front page with their addresses. As is often done, we locate the inventive activity represented by patents according to the address of the first inventor, using the coding in the NBER files. While this convention is not perfect, it ensures that each invention is counted in one and only one location.[6]

We focus on the number of patents and the quality of those patents as measured by citations by subsequent patents.[7] Citations are the number of times each patent is cited by all other patents, and we restrict our analyses to utility patents. Citations most often mean that other inventors are building on the inventions of others, but sometimes indicate an ongoing, successful stream of research within a given firm or university. These citations by definition only occur after a patent is granted. We examine citations in a five-year moving window including the year the patent is issued and the four subsequent years because patents typically receive few citations in the first few years after they issue. We track the number of patents from 1980 through 1998 for high-technology states. For citations, our data series ends in 1996; hence, our analysis of patent quality includes only patents granted up through 1992 in order to accumulate five years of citations for the newly issued patents.

Every patent reflects an invention by an individual inventor, and by definition has one or more individuals with addresses listed under inventor. Most, but not all, patents have assignees recorded at the time the patent is issued. From 1980 to 1998, when our data series ends, about one quarter of all patents either have no assignee or are assigned to an individual.[8] (For convenience, both nonassigned patents with rights retained by the individual inventors and those patents assigned to individuals are termed as having individual assignees.) Therefore, rights to about three quarters of patents are assigned by the inventors to one or more organizations. The bulk of assignees at issue are employers of the inventors, but some independent inventors are able to sell rights to their inventions before the patents issue and would also have assignees registered at issue. The patent lists both the name and address of each assignee at issue; our NBER data, however, lists only the first assignee and no address.

But the nauset (NBER) data series adds to the patent records a coding of the type of organization: Firm and individual assignee are most common, but we also have university, government, and hospital or lab assignees during the time period 1980 through 1996 (we were not able to update organizational type coding for 1997 and 1998). Here, we focus on changes in the frequency of two types of assignees, universities and business firms from 1980 through 1996 because of special interest in their role in creating and commercializing new discoveries and stimulating the development and growth of high-technology industries.

2.1. Overall Trends in Number of Patents

Figure 1 presents the number of utility patents granted annually 1980-1998 for the major high-technology states.[9] The large increase in patenting across the board in 1998, discussed above in relation to the increase in number of patent examiners, is the most striking feature of this figure. California's dominance and strong upward trend in patenting are both evident, above the general upward trend nationally in the number of patents granted during this time period. New York is a clear second, and Texas has moved up over time into third place. However, if we look at these same numbers relative to the states' population bases—as graphed in Figure 2 -- California

[5] Patent data for 1997 and 1998 were produced under contract by HZ Multimedia under the direction of James Zheng.

[6] Alternatively, patents might be located in each state or country in which an inventor appears, or 1/n patents could be counted in the location of each of its n inventors, or the address of the assignee (if any) could be used. The first of these approaches involves double counting for those patents with inventors located in different locations. The second approach is theoretically appealing but not possible with the available data set. The third is likely to be misleading, since the assignee's address is likely to be headquarters of the organization-not necessarily the location of either the inventive activity or application of the resulting technology. For more details, see the Appendix.

[7] Patent citations are reasonable indicators of relative quality of a patent. But the actual process of listing citations to other patents needs to be taken into account: While citations to other patents are initially proposed by the inventor (and/or the assignee and their respective patent lawyers), they are sometimes added to and/or subtracted from by the patent examiner in the US Patent and Trademark Office. Thus patent citations are not the same as a "citation" to an earlier scientific article.

[8] The percentage of patents with individual assignees is 26.7 in 1980, 25.0 in 1986, 24.7 in 1992, and 22.8 in 1996. See Table 1 and accompanying discussion below for details and complete percentage distribution of assignment of patents with U.S. first inventors.

[9] Utility patents are the standard type issued for new inventions and make up the vast bulk of all patents. Other types include design and plant patents.

manages to achieve third place only in 1998. In earlier years it lagged more significantly behind the leaders: Connecticut, New Jersey, Massachusetts, and Michigan.

California—like high-tech states generally—ranges 25 to 45 percent above the national norm in the per capita rate of patenting as shown in Figure 3. To present the information about the high-tech states in a summary form that is a little easier to read, we look at patents granted in 1980, 1986 and 1992. Figure 4 presents the results on utility patents granted, while Figure 5 presents the patents granted per 100,000 residents. Again, while California dominates in total number of patents, California loses its dominant position when we take the population base into account. If 1998 data were added, however, it would show increased strength of California relative to the other high-technology states both in absolute and relative terms.

2.2. Overall Trends in Quality of Patents

While patents granted is a good indicator of overall output of inventions and related commercialization activity, it does not measure how valuable the patent is relative to other patents. In Figure 6, we present the number of citations cumulated over five years to patents in 1980, 1986 and 1992.[10] We selected a five-year moving window to allow sufficient citations to accumulate to newly issued patents. Otherwise, since new patents have a low probability of being cited during the first few years after they have been issued, our measure would be biased against recent patents.

Among high-technology states, citations to patents are uniformly increasing over time. This in part is a result of an increasing number of patents granted (providing more new patents to cite those already granted), but California lags New Jersey, New York and Texas in citations to patents granted in 1980, leads all states in 1986, and all except Massachusetts in 1992.

To the extent that local patent citation is more likely (including cross-citations within the same organization or by the same individual), just having more patents granted in a state—especially highly concentrated within a few local areas, a few organizations, and a few highly productive individual inventors—may also directly lead to having more citations. Hence, we need to be cautious in interpreting number of citations as a pure quality measure.

[10] Because adding new data on citations from 1997 and 1998 involves recalculating all of the citations to patents granted in previous years, since current patents can cite any of the prior patents granted, we are not able to update citations at this time.

2.3. Inventive Activity by Assignee Type: The Role of Universities and Firms

Since assignees at issue are usually employers of the inventors, shifts in the distribution of these assignees give some indication of shifts in innovative activity among different kinds of organizations over time. We restrict our analysis by assignees to those with American first inventors since we are interested in the organizational structure of U.S. inventive activity. Figure 7 displays the numbers of patents granted for each type of assignee for 1980, 1986, 1992, and 1996. (We include the 1996 data because many of the comparisons we make in later figures change significantly between 1992 and 1996.) Most striking visually are the increases in business firms as assignees on patents, but university assignments actually have a much higher growth rate over these 16 years. As detailed in Table 1, the percentage distribution of assignees shifts over time toward firm and university assignees and away from government and individual (including no) assignees. Given the overall increase in numbers of patents during this time period, all sectors have increasing numbers of patents except for government which actually declines in raw numbers by about a quarter between 1980 and 1996.

Although the number of patents granted with university assignees is very low compared to firms, we are especially interested in tracking university patenting because of some evidence that university inventive activity spurs commercial activity nearby.[11] In Figure 8, we can see that the number of utility patents granted to universities has generally increased since 1980, possibly due to the passage of the Bayh-Dole Act of 1980 that allowed universities (and other federal contractors such as firms, hospitals, and labs) to patent inventions deriving from federally funded research. California universities lead in patenting activity, and have increased their patenting markedly relative to other high-technology states, especially after 1992.

After adjusting for state population, California universities drop relative to other high-technology states, though by 1996 California universities are in third place with only Massachusetts and Wisconsin universities patenting more per capita (Figure 9).

Turning to the number of utility patents assigned to business firms, we can see in Figure 10 that California has a small lead in 1980 over other high-technology states. As shown in that Figure, California increased its

[11] Evidence of geographically localized knowledge, often attributed to knowledge spillovers, is reported in the references cited in footnote 2 above.

Table 1. Percentage Distribution of Patent Assignees at Time Patent is Granted with American First Inventors, 1980, 1986, 1992, and 1996

Assignee Type	1980	1986	1992	1996
Firm	68.6%	70.2%	69.7%	71.8%
University	1.0%	1.7%	2.9%	3.4%
Government	3.3%	2.7%	2.2%	1.5%
Hospital or Lab	0.3%	0.4%	0.5%	0.5%
Total—All Organizations	73.3%	75.0%	75.3%	77.2%
Individual[a]	26.7%	25.0%	24.7%	22.8%
Total—All Utility Patents[b]	100.0%	100.0%	100.0%	100.0%

Totals may not add due to rounding.

[a]The assignee is coded as an individual assignee if the patent is assigned to one or more individuals at issue or if no patent assignment has been registered by the time the patent is granted so that the individual inventors retain their rights to the invention.

[b]Calculations are based only on those utility patents in each year for which the first inventor lists an American address.

lead at a strong pace over time, especially after 1986, with consistently positive increases after 1990. In per capita terms, however, California firms only achieve fifth place among the high-tech states by 1995-1996.

Turning now to the bar charts, we again review the same data but in a way that highlights the change over time. In Figure 12, the increase in patenting by universities in California in 1996 is especially striking, with patenting activity nearly double that of the closest rival states. However, as shown in Figure 13, Massachusetts has about three times the university patents as California per capita in 1996. California's consistent lead over other high-tech states in number of patents assigned to firms is shown in Figure 14. When examined on a per capita basis in Figure 15, both California's middle positioning and rapid improvement in firm patenting is evident.

3. California vs. Massachusetts: Inventive Activity and Quality

California and Massachusetts are directly compared as soon as the words "high tech" are mentioned. The two states often see themselves as competitors, and social scientists describe both Silicon Valley stretching between Stanford and San Jose and Route 128 around Boston as incubators of high-tech industry (see especially Saxenian 1994).

For just these two states, it is very clear in Figure 16 that California has a wide lead in number of patents granted and the lead is increasing over time. However, when we normalize on the state population base in Figure 17, California loses its lead to Massachusetts, but Massachusetts does not increase its lead over time in the 'patent race' between the two states. In quality of patents, as measured by citations per patent over a five-year period, California and Massachusetts are very evenly matched over time as shown in Figure 18. For patent citation comparisons, we must restrict our analyses to patents granted between 1980 and 1992 as explained above.

4. Major High-tech Fields

We focus on three major high-technology fields—biotechnology, semiconductors, and computer-related. To examine patenting in these subareas, we select specific patent classifications that are listed in detail in Appendix Table A.1. Construction of these patenting area definitions was supported by UC Systemwide programs.[12] In each of these high-tech industrial fields, we first do a detailed comparison between California and Massachusetts making apparent the trends and fluctuations over time and then turn to a comparison among high-technology states.

4.1. Biotech-Related Patents

Figure 19 shows that California has had a consistent lead over Massachusetts in the number of biotech-related utility patents granted, a lead that is increasing especially in the 1996 through 1998 period. Even when we normalize on the population base in the two states, California and Massachusetts are very close to each other

[12]We are indebted to support from the University of California Systemwide Biotechnology Research and Education Program and from the University of California President's Office Industry-University Cooperative Research Program which supported data purchase and analysis for the high-technology areas biotechnology, semiconductors, and computer-related. In other research reports, we use a broader definition of patent classes for each of these high-technology areas; for simplicity of exposition, we restrict our analyses here to the "pure" patent classifications.

during the early to mid-1980s, with Massachusetts pulling away after 1986 (see Figure 20). Patent quality shows an interesting pattern in Figure 21, with California and Massachusetts initially quite close, California pulling away in the mid 1980s, and Massachusetts catching up and converging in the late 1980s and early 1990s. Overall, though, California has higher average citations to its patents in biotech.

Returning to comparisons of 1980, 1986, and 1992 for all high-tech states,[13] Figure 22 presents some interesting comparisons among the states in the number of biotech-related utility patents. It appears from this figure that Massachusetts is not the main competitor in this area with California, but rather it is New Jersey with its heavy concentration of pharmaceutical companies and related science. We know from other research that Massachusetts has a very strong science base in molecular biology and bio-chemistry, but its scientists and bio-engineers did not have the same degree of success in patenting as California's during the early to mid-1980s. Even when we normalize on state population in Figure 23, Massachusetts only surpasses California in 1992 and New Jersey continues to dominate. The persistent strength of Connecticut is also remarkable while Pennsylvania has not maintained its relative position.

Patent quality, as measured by the average number of citations by other patents, does not follow the same pattern, as shown in Figure 24. Again, the number of citations per patent are based on five-year moving windows. California is second only to Connecticut in 1980 and a clear first in patent quality in 1986, but by 1992 New Jersey and Pennsylvania surged ahead and California was in a close race for third place with Massachusetts, Illinois, and Texas. The dramatic improvement in the quality and quantity of Texas's patents is even more dramatic for semiconductors and computer-related patents (see below).

California's striking growth in the early 1980s to a position of dominance in the mid-1980s (1986 measurement), and subsequent relative decline on our patent measures mirror common understandings and emerging concerns in the 1990s within the biotech industry in California.

4.2. Semiconductor-Related Patents

The total number of patents granted to California in semiconductor-related areas is consistently above Massachusetts, as shown in Figure 25. For patents per capita, as shown in Figure 26, California and Massachusetts were running a very even race through 1993. But the last five years of data suggest that California is consistently and strikingly pulling ahead. Patent quality in Figure 27 also shows a mixed pattern, but California patents generally receive slightly higher citations per patent than Massachusetts semiconductor-related patents.

Comparing among the high-tech states, Figure 28 shows that California's main competitor in semiconductor-related patents is now Texas, not Massachusetts (again, keeping our last year in bar charts as 1992). In fact, New Jersey and New York (and even Pennsylvania in 1980) produce more patents in this area than Massachusetts. Normalized on population, Texas actually has the largest number of patents in this area by 1992, taking away New Jersey's dominance in the 1980 and 1986 periods (Figure 29).

In Figure 30, semiconductor-related patent quality as measured by five-year moving windows shows a highly variable pattern across states. We think that the shifts are probably due to technology changes, and to "catch ups" in technology (or the underlying science) by other states (or universities within the state). Michigan is dominant in 1980 but the actual number of patents being cited is very small; in fact for 1981 patents New York was the leader. Washington and Illinois emerge as leaders in 1986, and patent quality is more evenly spread in 1992. The intellectual property base appears to be highly volatile over time, suggesting continuing inventions that become building blocks for technology shifts.

4.3. Computer-Related Patents

Again, California produces consistently more computer-related utility patents than does Massachusetts (Figure 31). Since 1992, California's lead has been increasing, sometimes dramatically. But on a per capita basis, the dominance shifts to Massachusetts until 1996, with the lead shifting strongly to California in 1997 and 1998 (Figure 32). Patent quality as graphed in Figure 33, shows Massachusetts patents generally ahead of California in number of citations per computer-related patent, but California led in 4 of the 13 years.

Comparing to all high-tech states, Figure 34 confirms California's leading position in number of computer-related patents. Texas, Massachusetts and New York are the other major innovation sites by 1992 (once again, these bar charts are not updated). On a per capita basis, however, Massachusetts has taken a clear lead with

[13] We do not add the 1996 year here as we did in the prior section of this report as discussed earlier.

California and Connecticut patenting less than half as frequently in 1992 on a per-capita basis (Figure 35).

There is no clear leading state in patent quality. The lead among the high-tech states has changed frequently. For 1992 patents, California and Texas lead in patent quality, but there are numerous close competitors (Figure 36).

4.4. California's Biotech-, Semiconductor- & Computer-Related Patents

In terms of total number of utility patents granted, California outperforms the other high-tech states in patents related to the biotechnology, semiconductor, and computer industries. Per-capita patents provide a somewhat different story. We have not yet fully explored the very recent changes in population-adjusted patent rates, but based on our California/Massachusetts comparisons it seems likely that in at least two of the areas−semiconductor and computer−California has now moved up strongly, even on a per capita basis.

In the past, however, California generally lost its top position on a per capita basis, even though falling generally within the top three or four states. This suggests that California is performing very well over all in the high-tech areas, but not fully proportional to it large population base at least in some areas of high technology. California lost ground in biotechnology once the incumbent pharmaceutical companies concentrated in New Jersey adopted the new technology (Zucker and Darby 1996a and 1997, Darby and Zucker 1999).

In judging the quality race, we don′t yet have the advantage of data on the 1997 and 1998 patent citations. These citations are likely to make important additions if only because the increase in the number of patents has been so dramatic especially in 1998 with its 31.5 % increase in patenting over 1997. On the basis of our present data, California is losing ground in biotechnology, again to New Jersey. New Jersey takes over as leader in citations to its 1992 patents, with Pennsylvania moving into second place. Massachusetts, Illinois, and Texas are near California in citations 1992-1996 to 1992 patents granted.

In semiconductors, there is considerable variance across the time period in which states lead on patent quality. In computer-related patent quality, California′s relative position has improved over time, with California and Texas virtually tied for first place in citations to 1992 patents, just ahead of Massachusetts, Illinois, and New Jersey.

5. Implications and Conclusions

We have reviewed considerable evidence of California's strength in both creating and commercializing innovations as indicated by patent statistics and their change over time. But there is also evidence that California's accomplishments are not proportional to its size, and hence there is considerable room for improvement: California dominates in terms of overall patents granted, but not when we scale by population size. California's patent quality makes it a strong (but not dominating) competitor among the top high-tech states. The question of whether California is living up to its promise or under-performing remains a crucial, open issue.

Our overall results suggest room for some optimism, especially given more recent upward trends in the data, but also suggest that California is under-performing given its resource base. California has a patent base that is the largest in the nation. Since California is large relative to most other states, its dominance is not surprising. Its size certainly explains part of the effect, but California results are sometimes striking even after adjusting for population size. California rises to among the top five in recent years in total patenting per capita, rising to third in per-capita patenting by 1998, barely edging out New Jersey.

California sometimes leads in overall patent quality, and is just slightly behind Massachusetts and narrowly leading New Jersey and Texas on our most recent overall measure (citations to 1992 patents). Patent quality tends to be congested, with a number of high-tech states having roughly equal citations. Patent citations indicate not only quality but also widespread building on a patented invention. Thus, there are two ways to interpret these findings: We can emphasize California′s reasonably strong, but shifting, competitive position relative to other states or we can emphasize the benefits that flow not only to California but also to other states and countries from inventions made and commercialized by California.

One of our most interesting results is the increase in patenting by California universities from 1980 through 1996, both in absolute terms and relative to increases in other high technology states. Patenting by firms shows a similar pattern. The major contributions to invention by both universities and firms in California are indisputable. However, on a per capita basis, we once again must conclude that California is under-performing, especially in patenting by firms that rank fifth by 1996.

Despite the press coverage that suggests California and Massachusetts are neck and neck across many high-tech areas, the closest competitor with California depends on the technical area. In biotech-related patents, New Jersey is a stronger competitor than Massachusetts; in semiconductor-related patents it is Texas; and in computer-related patents it is nearly a toss-up between Texas and Massachusetts. For all three technical areas, California lags behind at least two other states on a per capita basis. Again, the question of under-performing given the California state resource base needs to be addressed.

Patent quality presents a very different picture of the patent race. Swings over time in both semiconductor- and computer-related patent citations are sharp enough that the early leading states drop out of the top group completely by the end of our time frame, and new states not formerly in the top group enter. Biotech-related patents present a different picture. Here, quality is clearly differentiated and California is top in 1986 but falls to among four contestants for third place in 1992.

There is little room for complacency but also considerable cause for optimism in our review of patenting activity and quality in California. The state has to run hard just to stay even with its vigorous competitors, but it has done a good job of doing that and better of late.

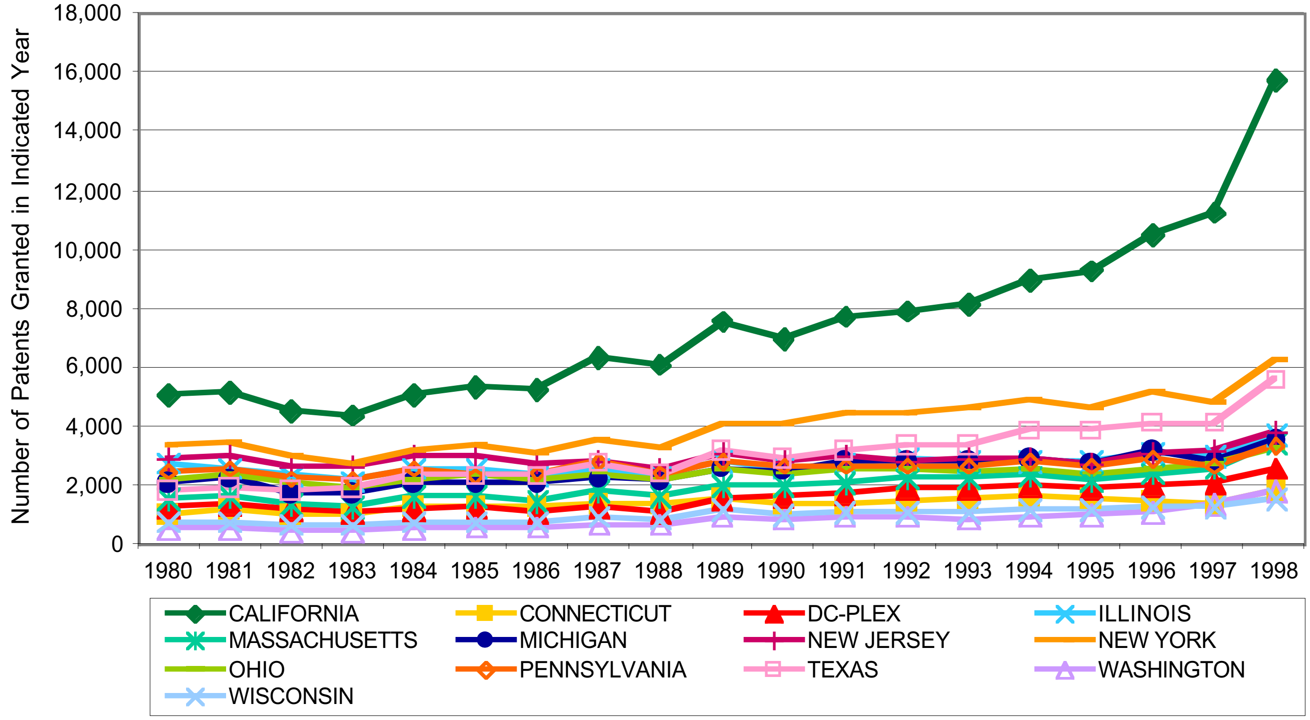

Figure 1. Utility Patents Granted for High-tech States, 1980-1998

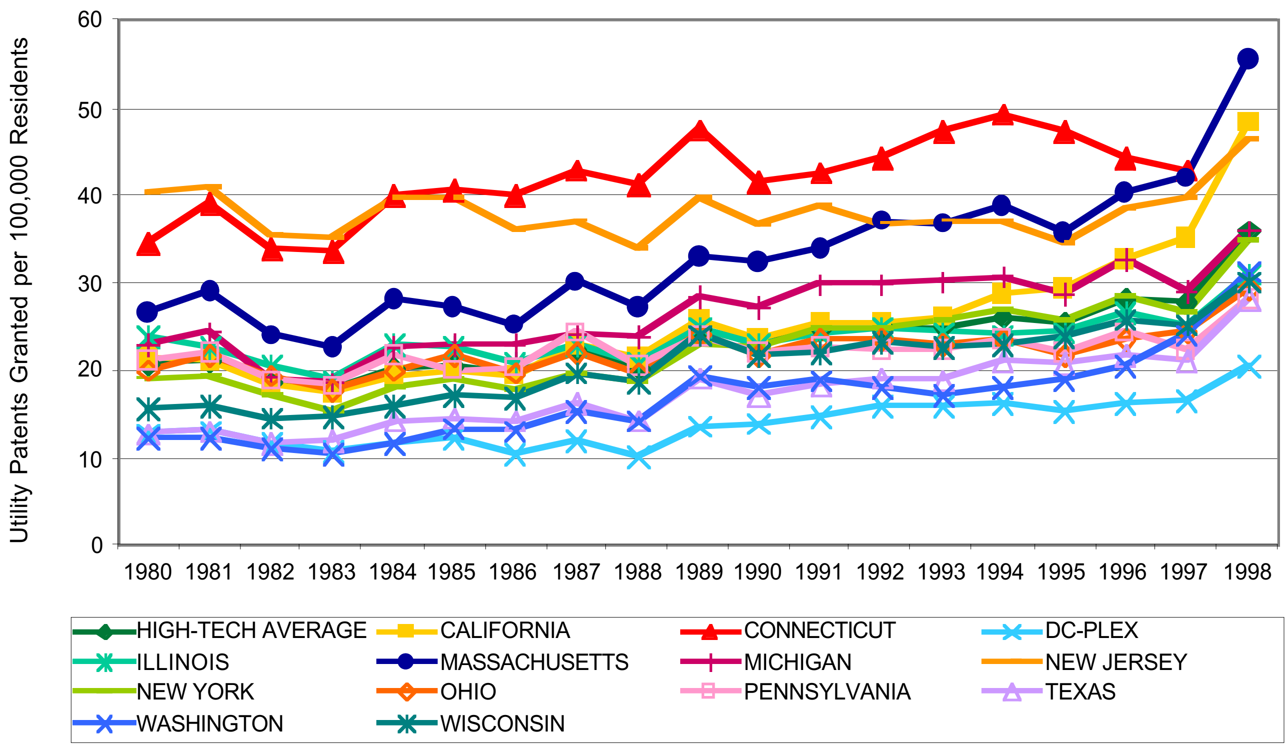

Figure 2. Utility Patents Granted per 100,000 Residents: High-tech States, 1980-1998

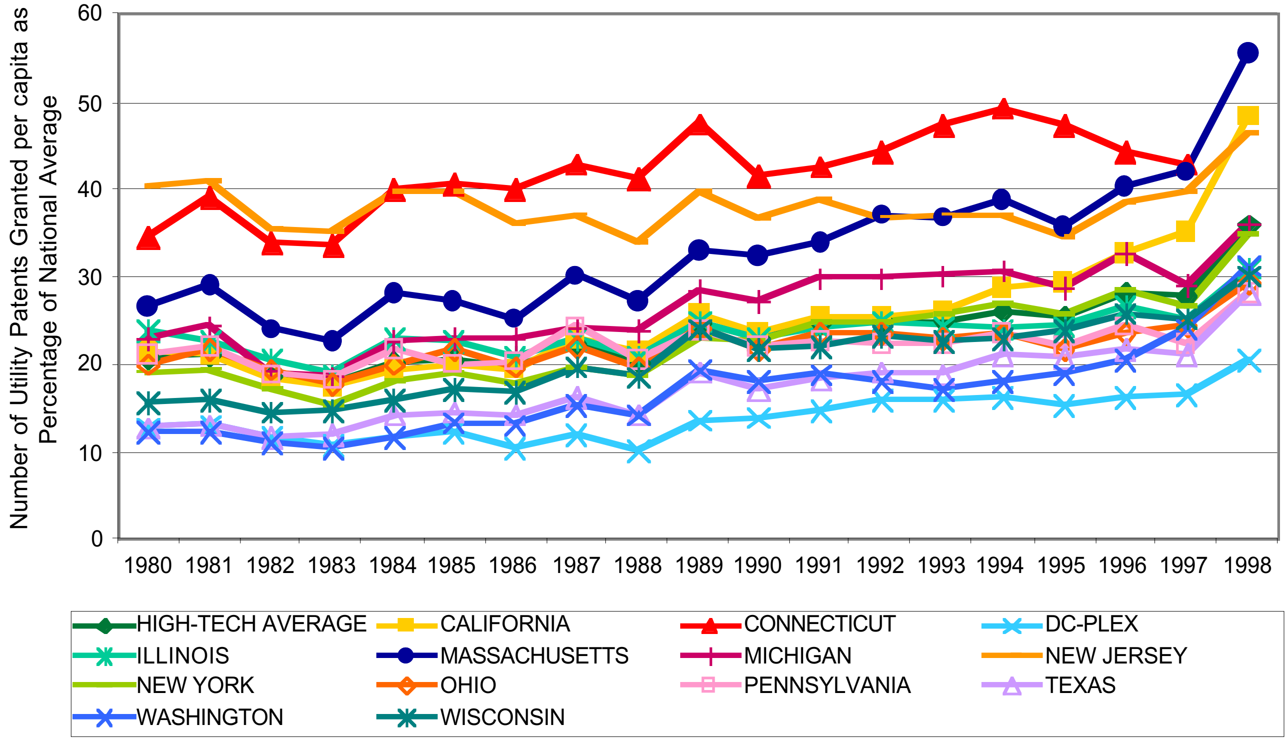

Figure 3. Utility Patents Granted per capita as Percentage of National Average: High-tech States, 1980-1998

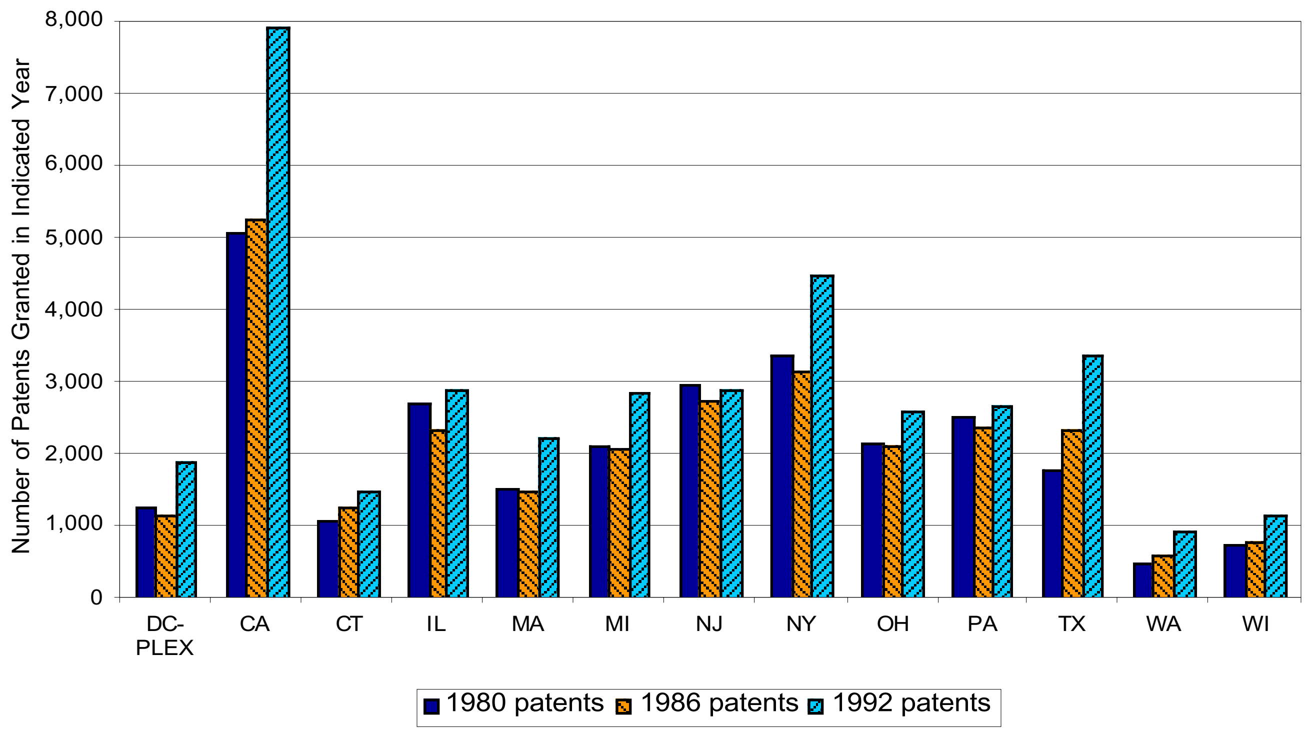

Figure 4. Utility Patents Granted to Inventors in High-tech States: 1980, 1986 and 1992

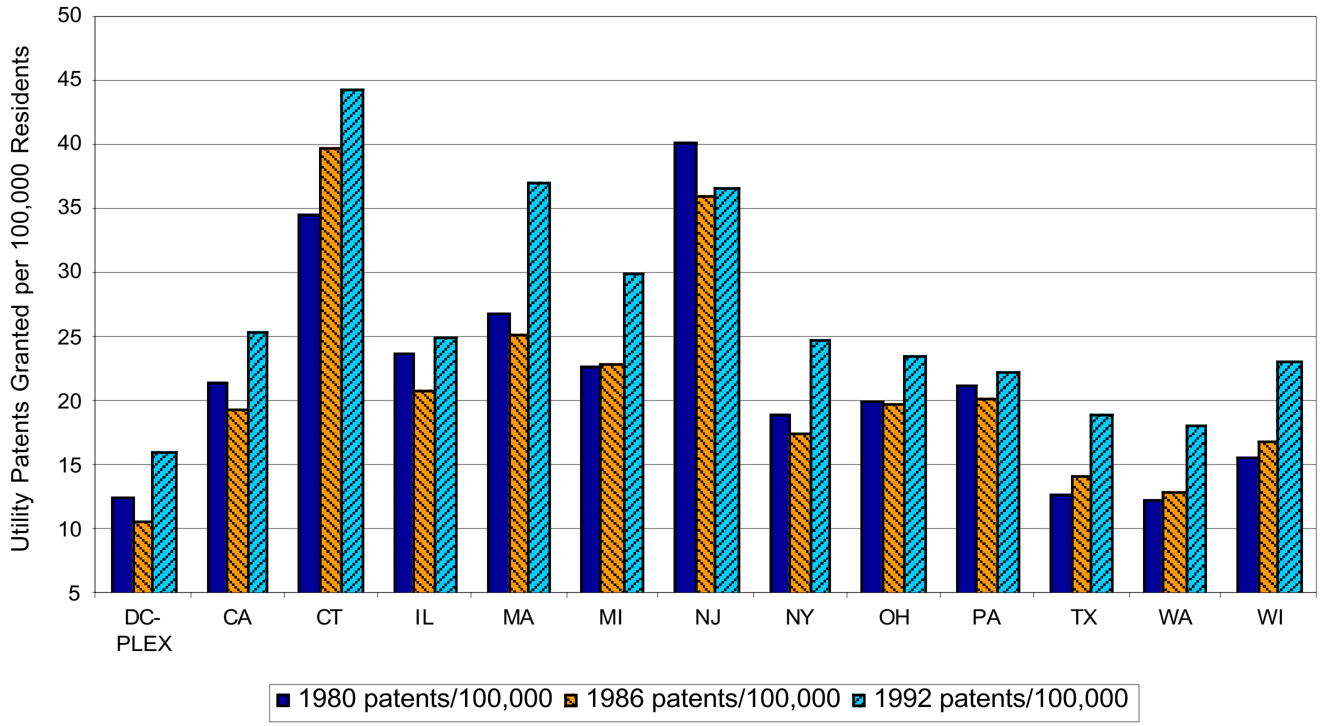

Figure 5. Utility Patents Granted per 100,000 Residents: High-tech States, 1980, 1986 and 1992

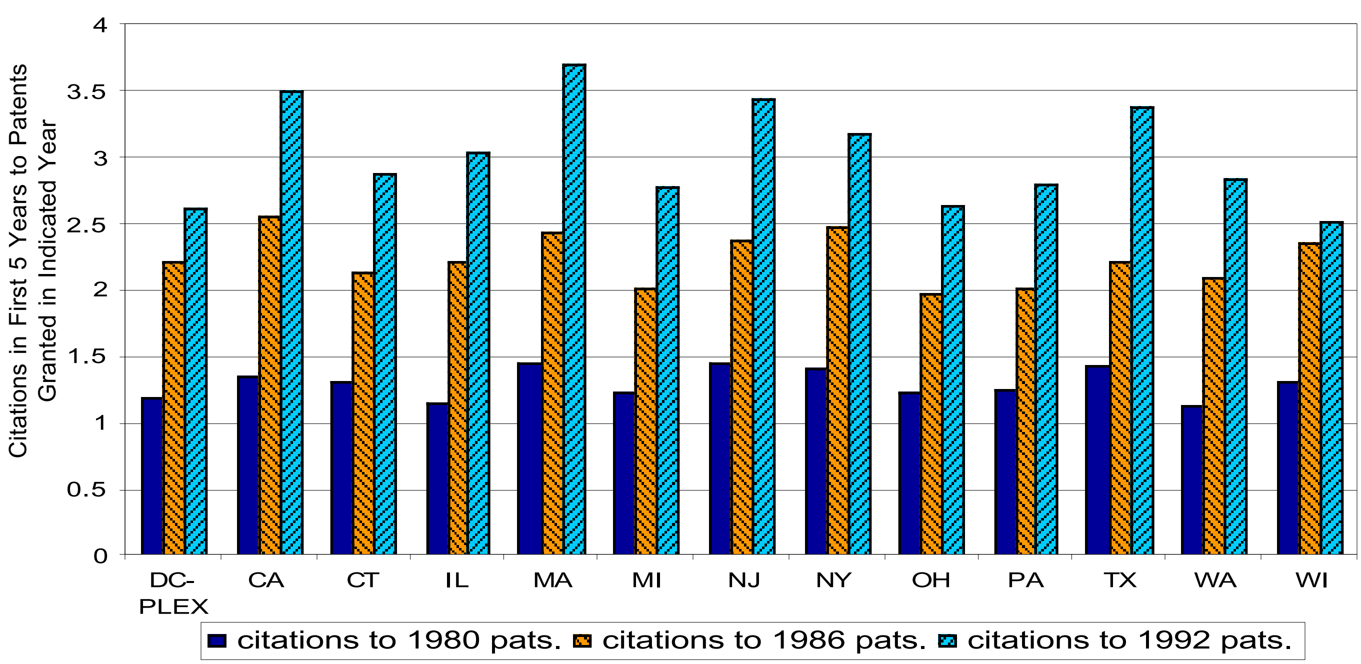

Figure 6. Patent Quality in High-tech States: 1980, 1986 and 1992

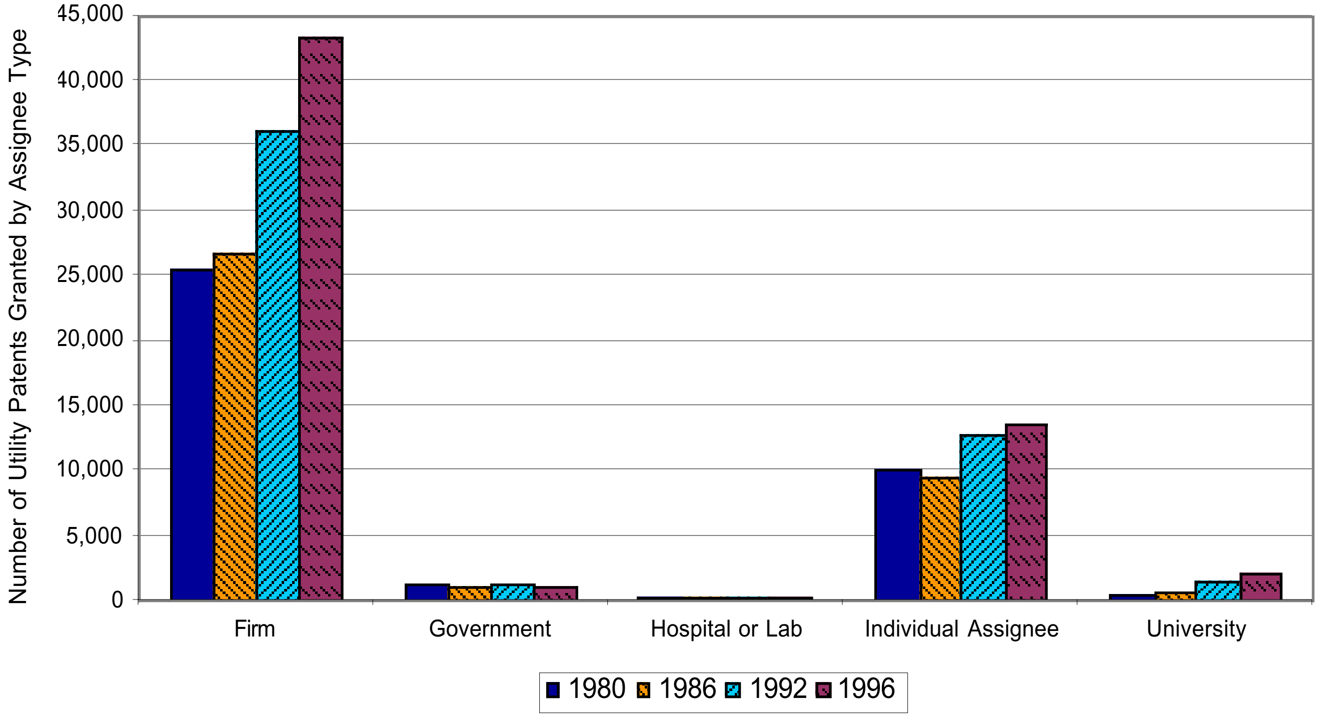

Figure 7. National Total Number of Utility Patents Granted by Assignee Types: 1980, 1986, 1992 and 1996

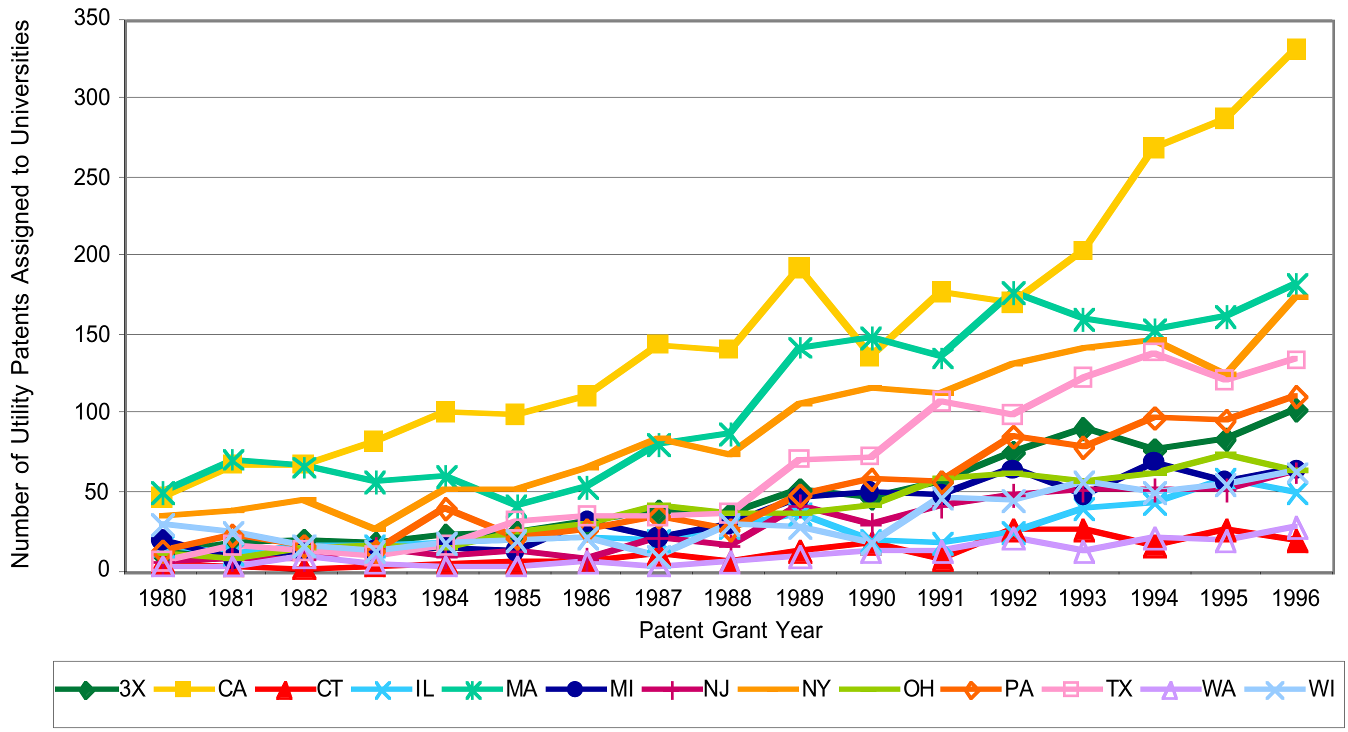

Figure 8. Utility Patents Assigned to Universities when Granted: High-tech States, 1980-1996

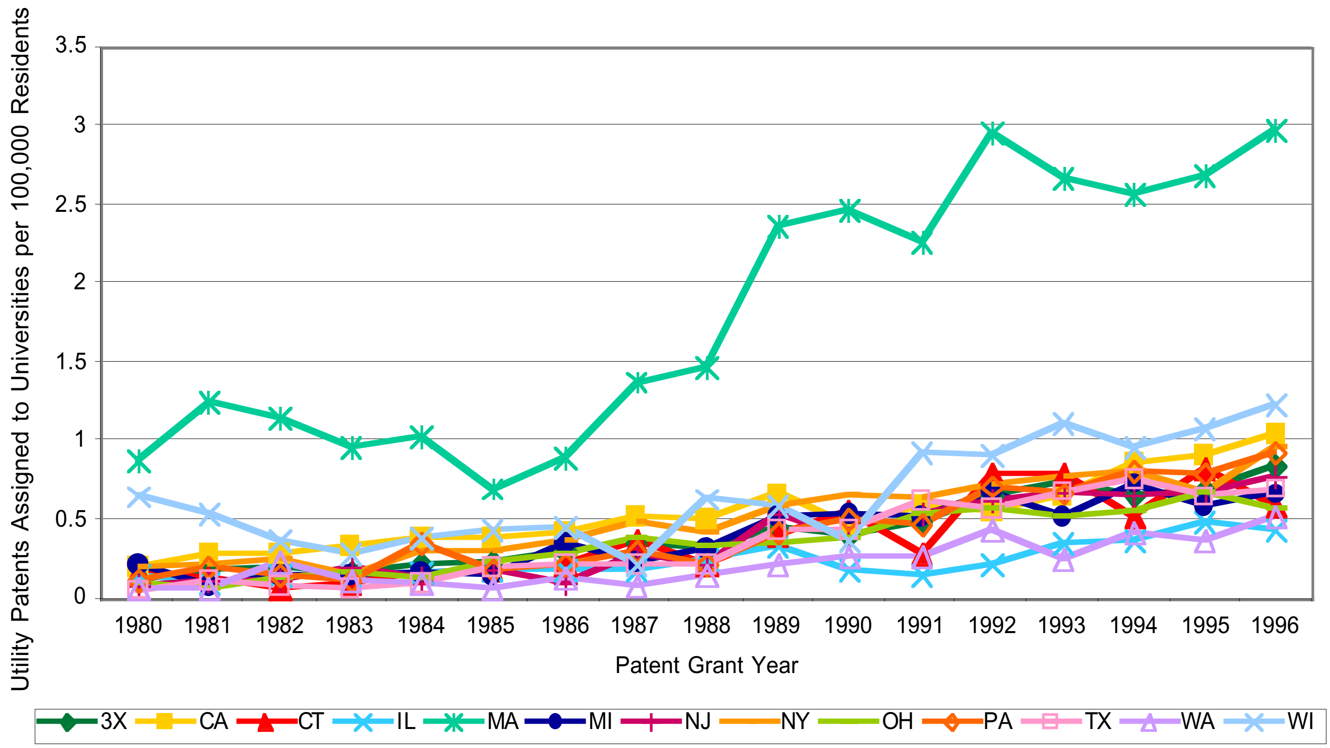

Figure 9. Utility Patents Assigned to Universities per 100,000 Residents: High-tech States, 1980-1996

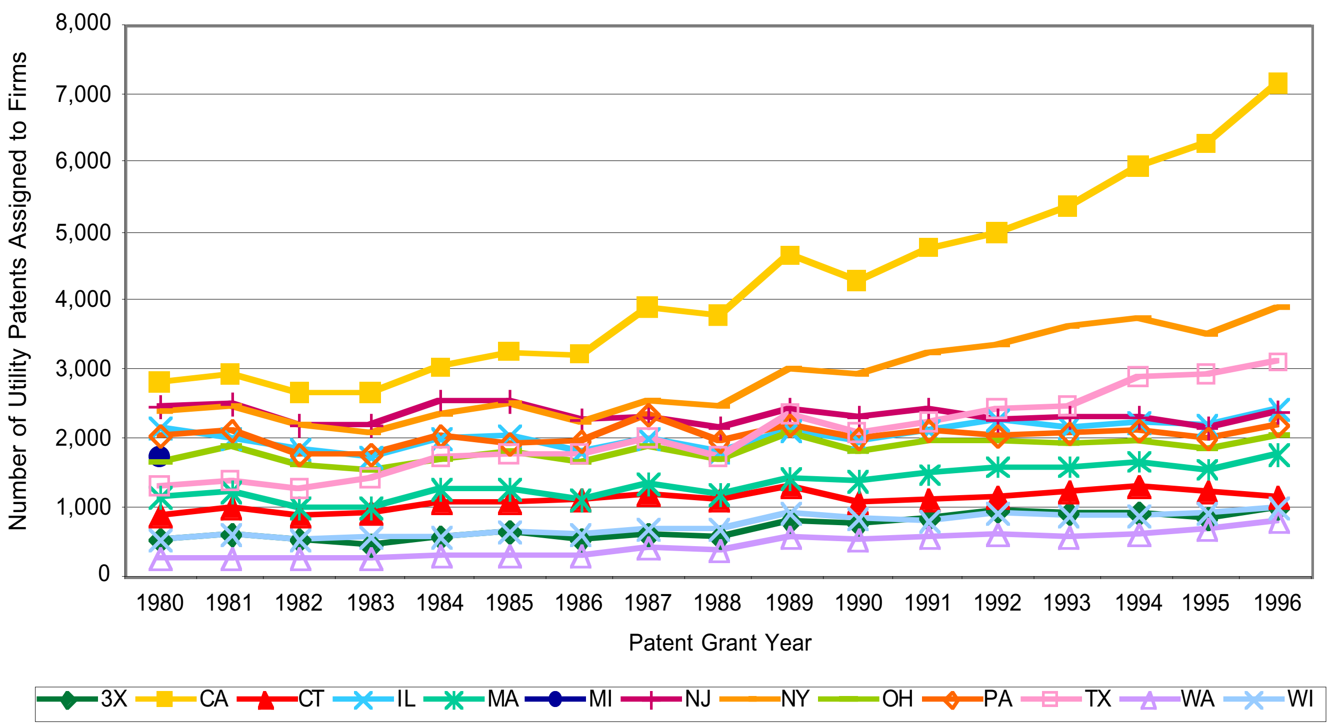

Figure 10. Utility Patents Assigned to Firms when Granted: High-tech States, 1980-1996

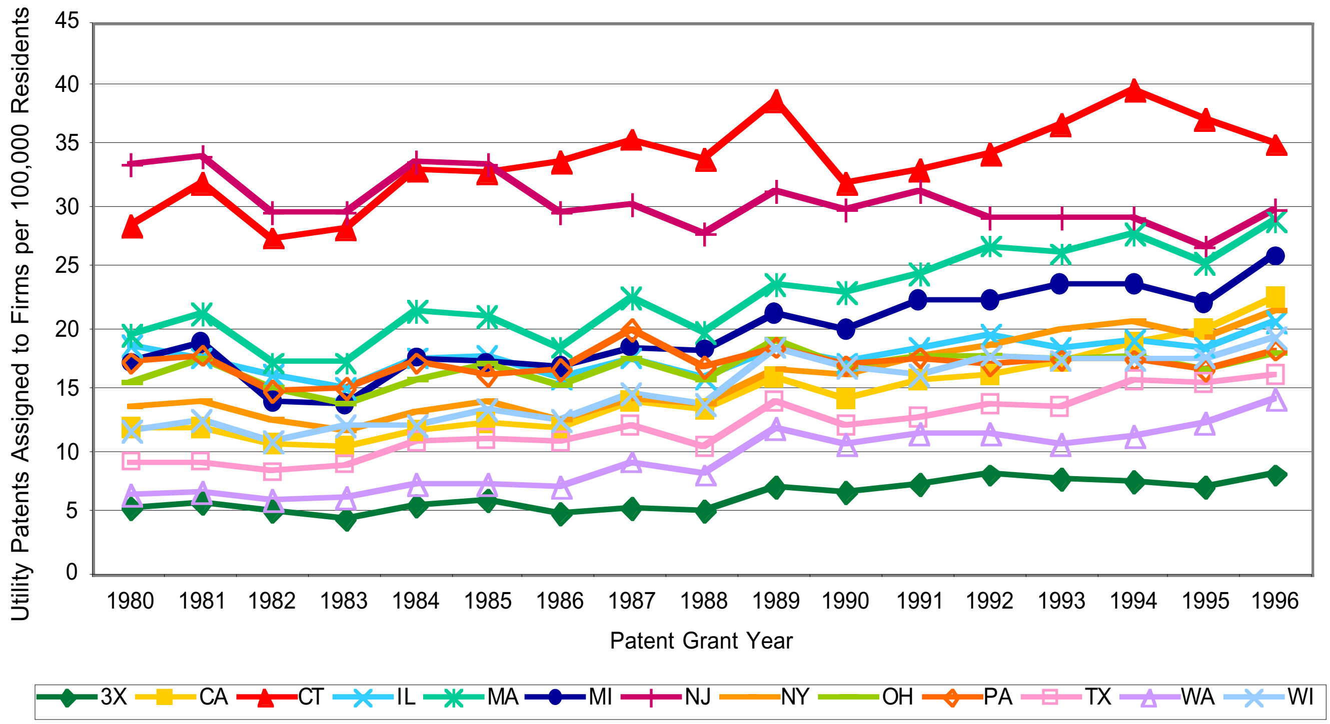

Figure 11. Utility Patents Assigned to Firms per 100,000 Residents, High-tech States, 1980-1996

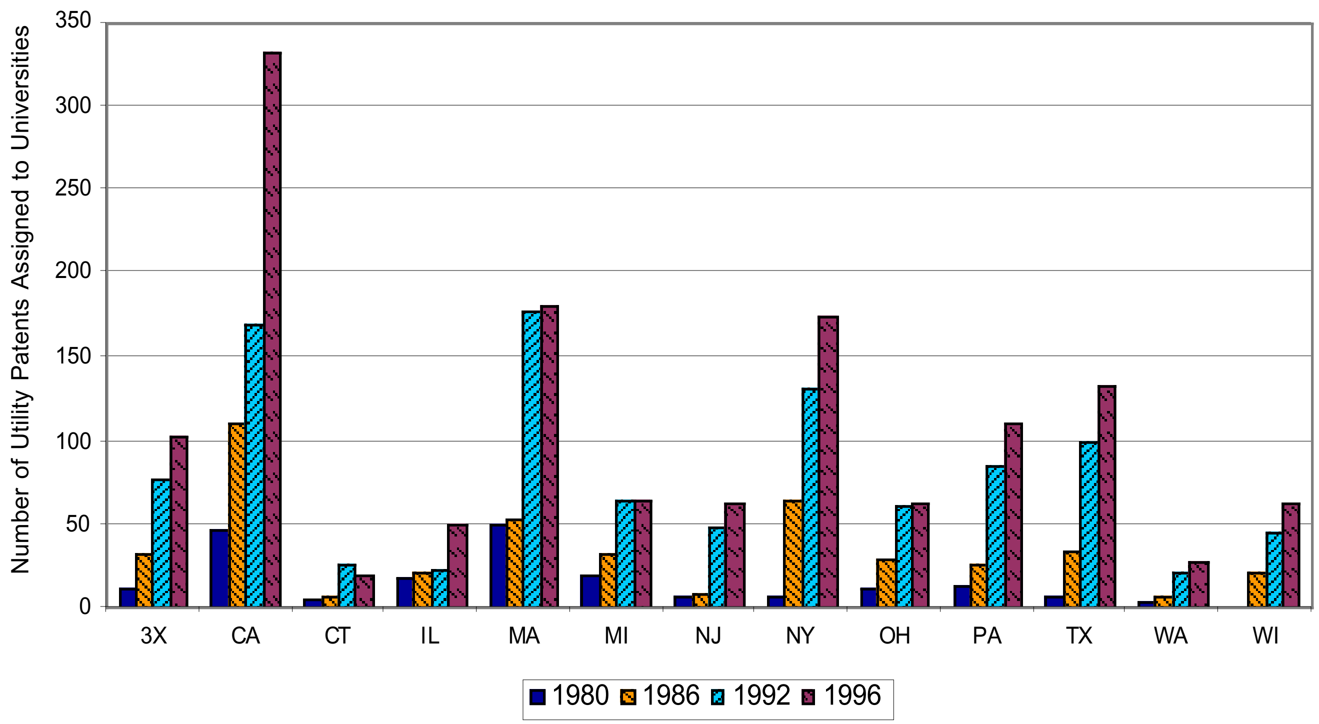

Figure 12. Utility Patents Assigned to Universities when Granted: High-tech States, 1980, 1986, 1992 and 1996

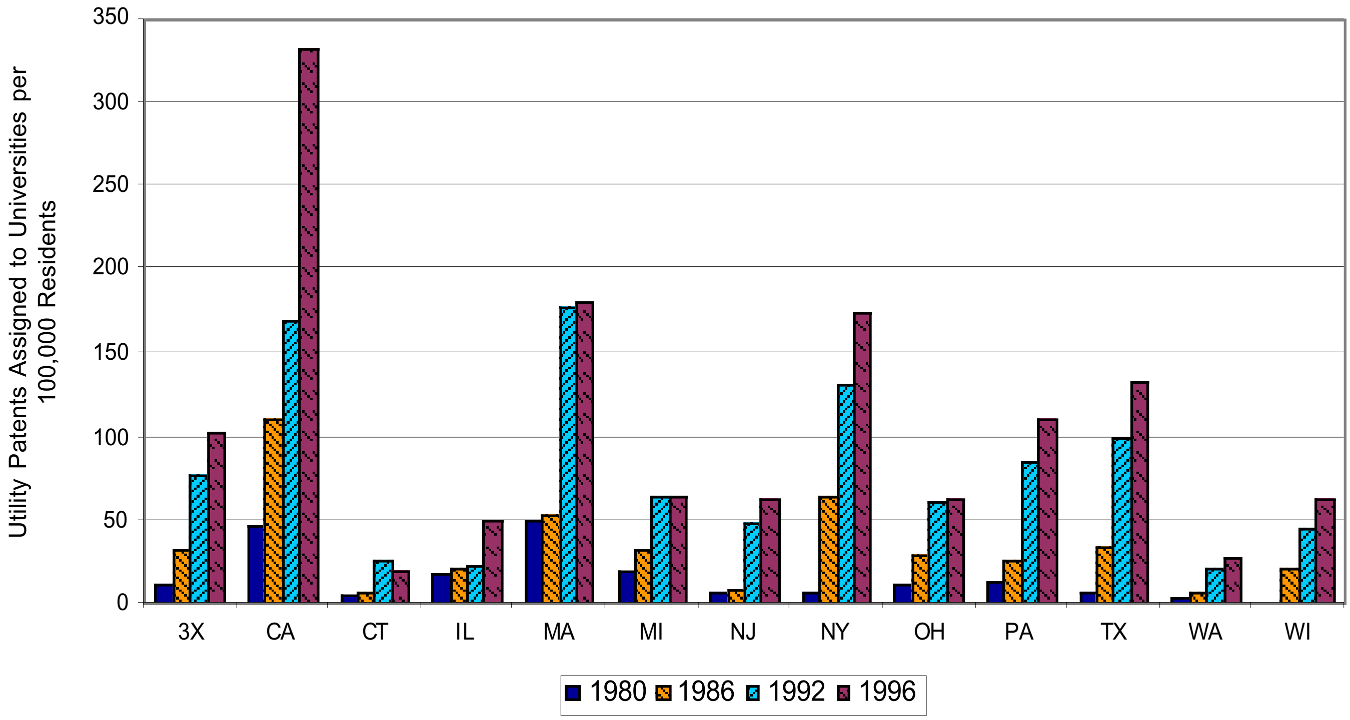

Figure 13. Utility Patents Assigned to Universities per 100,000 Residents: High-tech States, 1980, 1986, 1992 and 1996

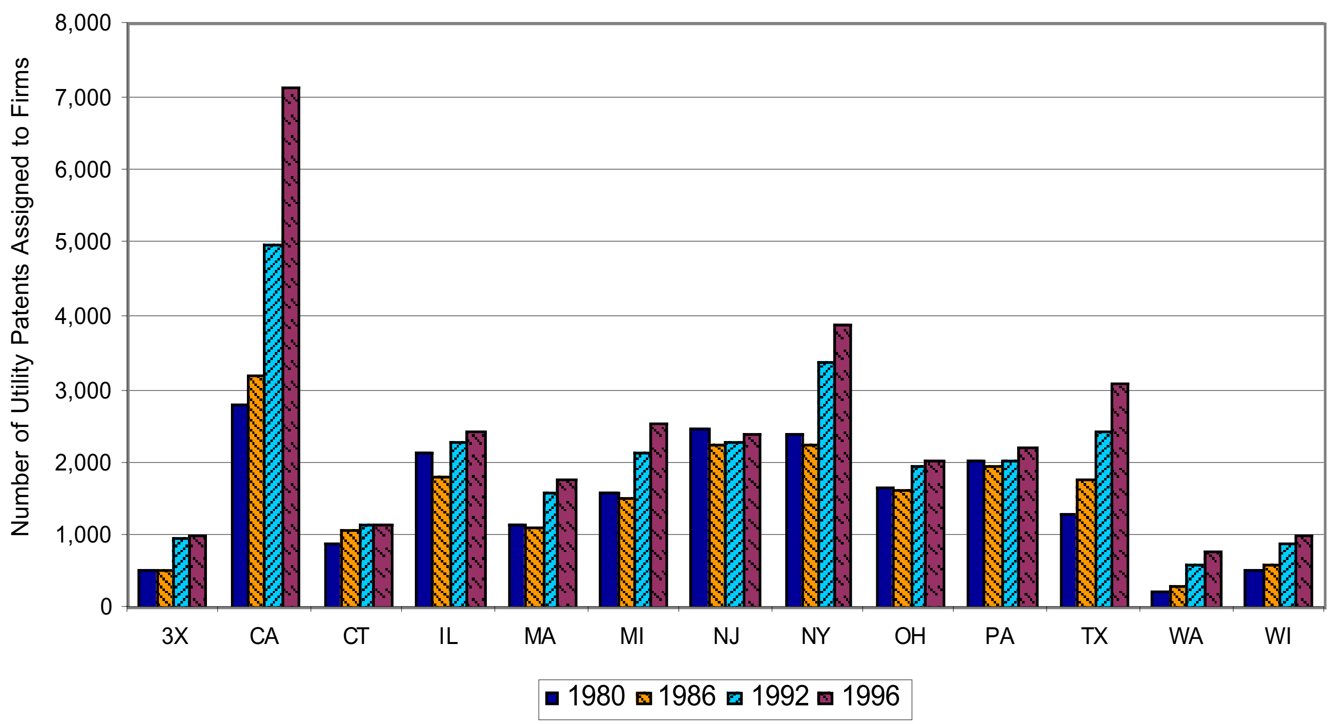

Figure 14. Utility Patents Assigned to Firms when Granted: High-tech States, 1980, 1986, 1992 and 1996

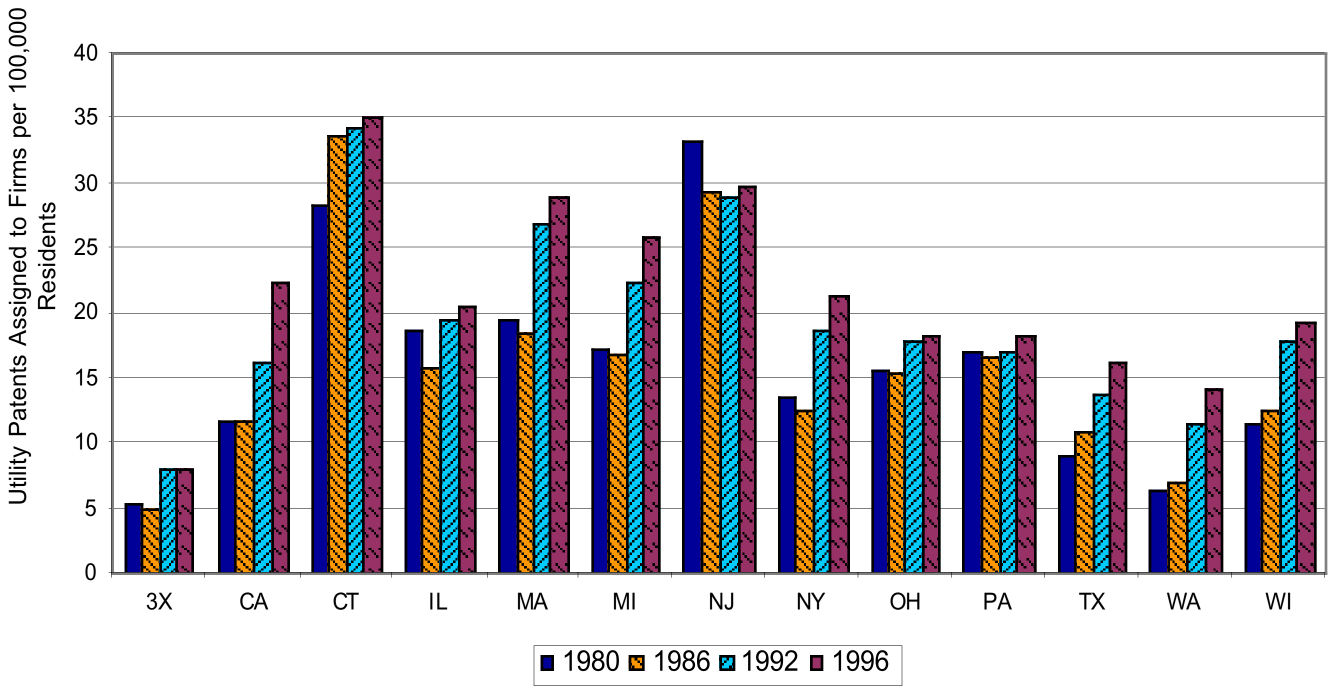

Figure 15. Utility Patents Assigned to Firms per 100,000 Residents: High-tech States, 1980, 1986, 1992 and 1996

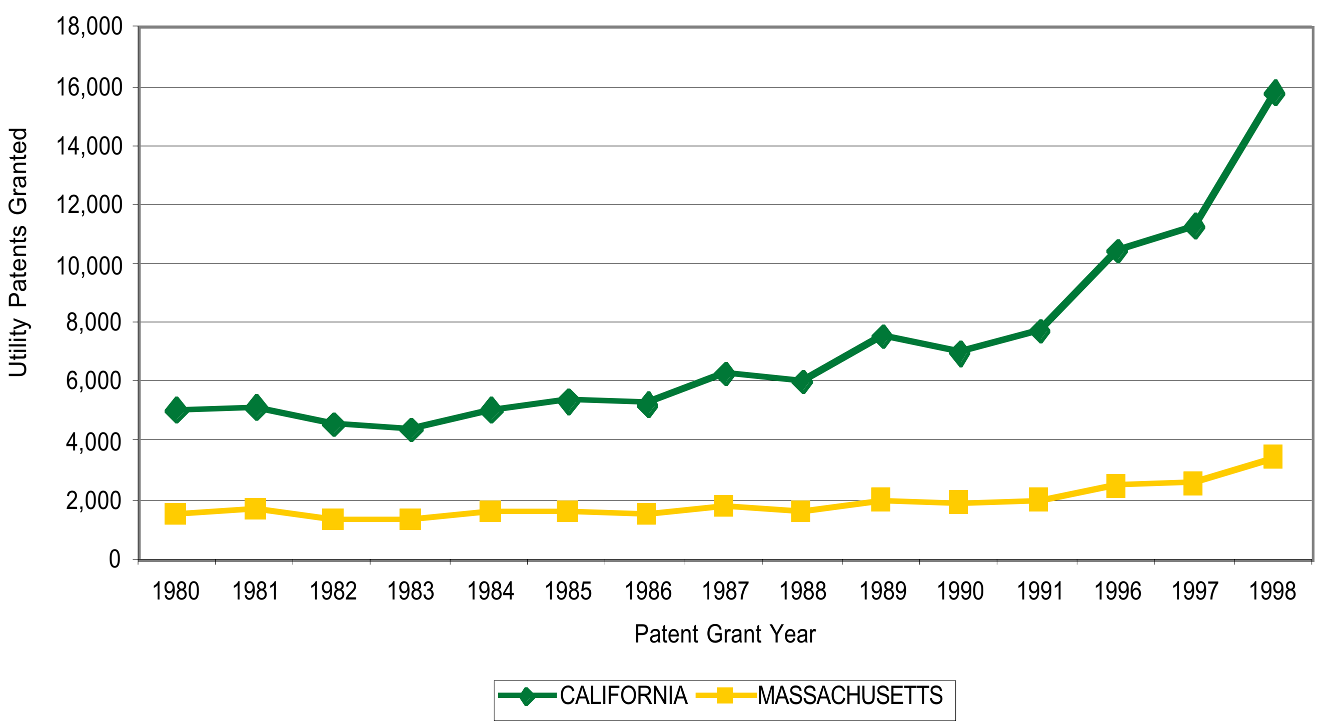

Figure 16. California vs. Massachusetts: Utility Patents Granted, 1980-1998

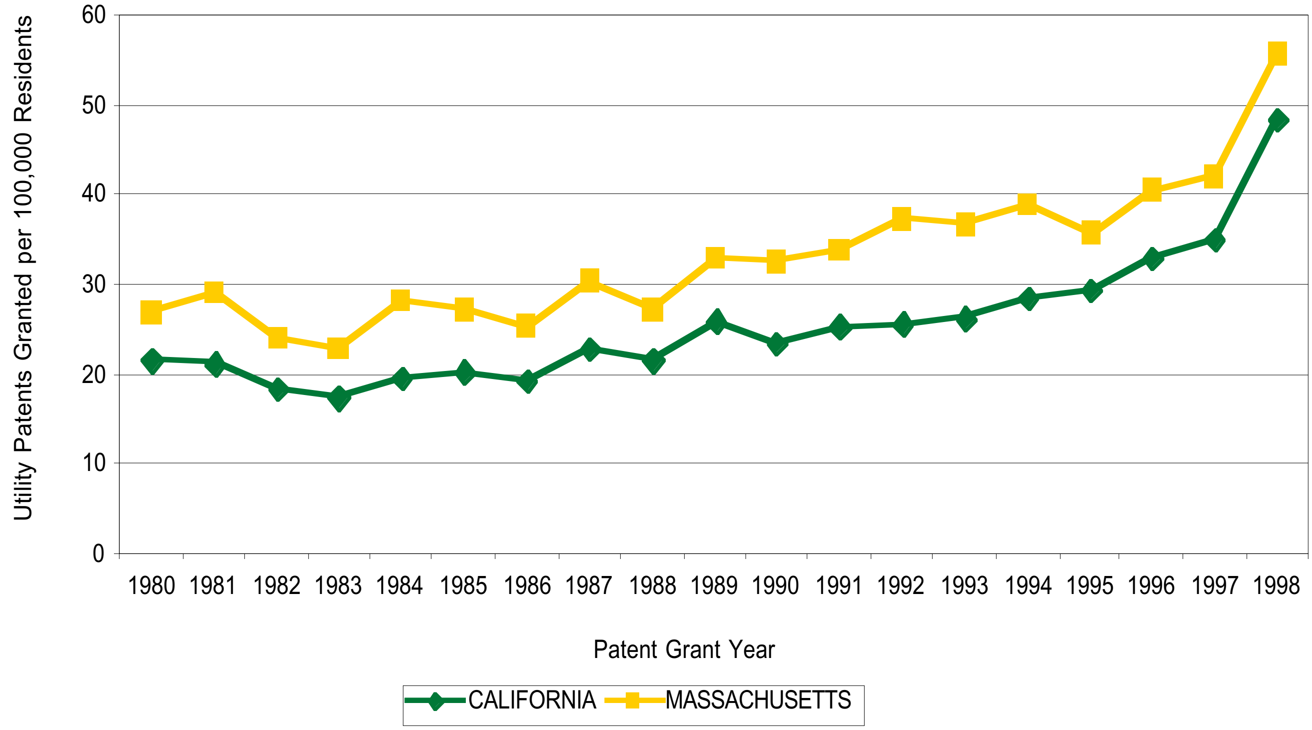

Figure 17. California vs. Massachusetts: Utility Patents Granted per 100,000 Residents, 1980-1998

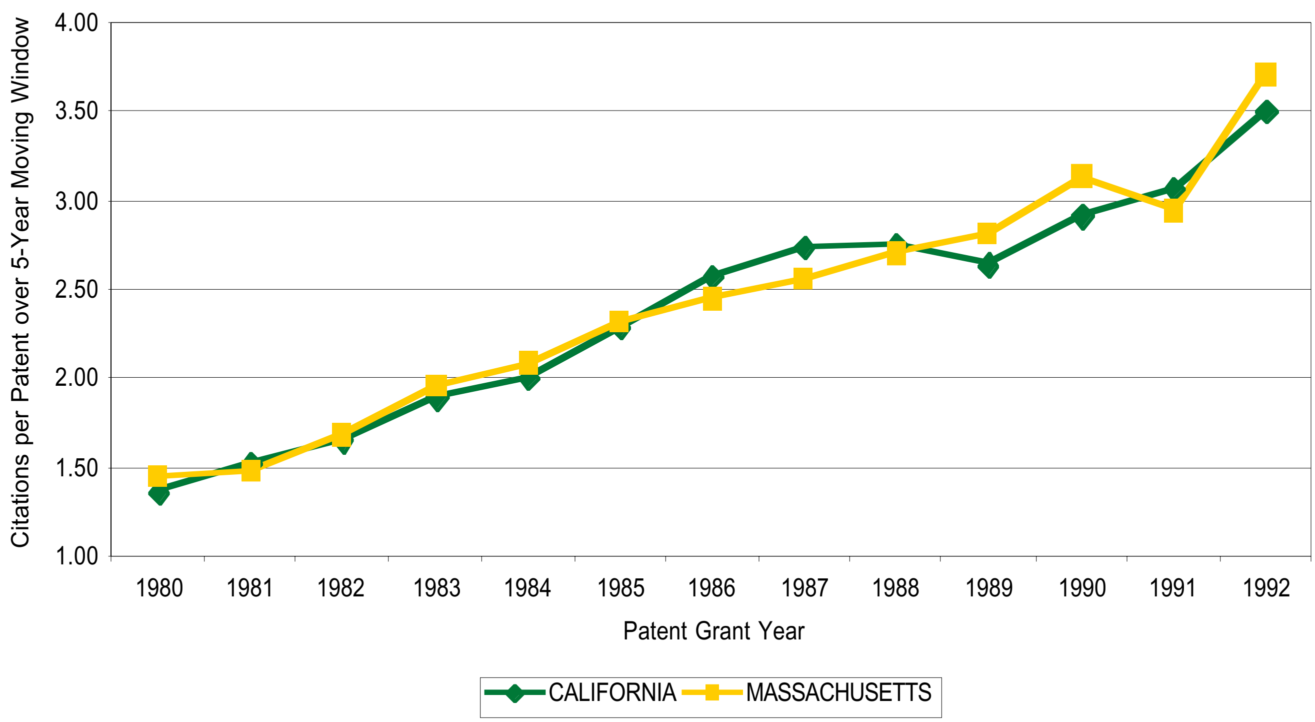

Figure 18. California vs. Massachusetts: Patent Quality, Citations per Patent over 5-Year Moving Window, 1980-1992

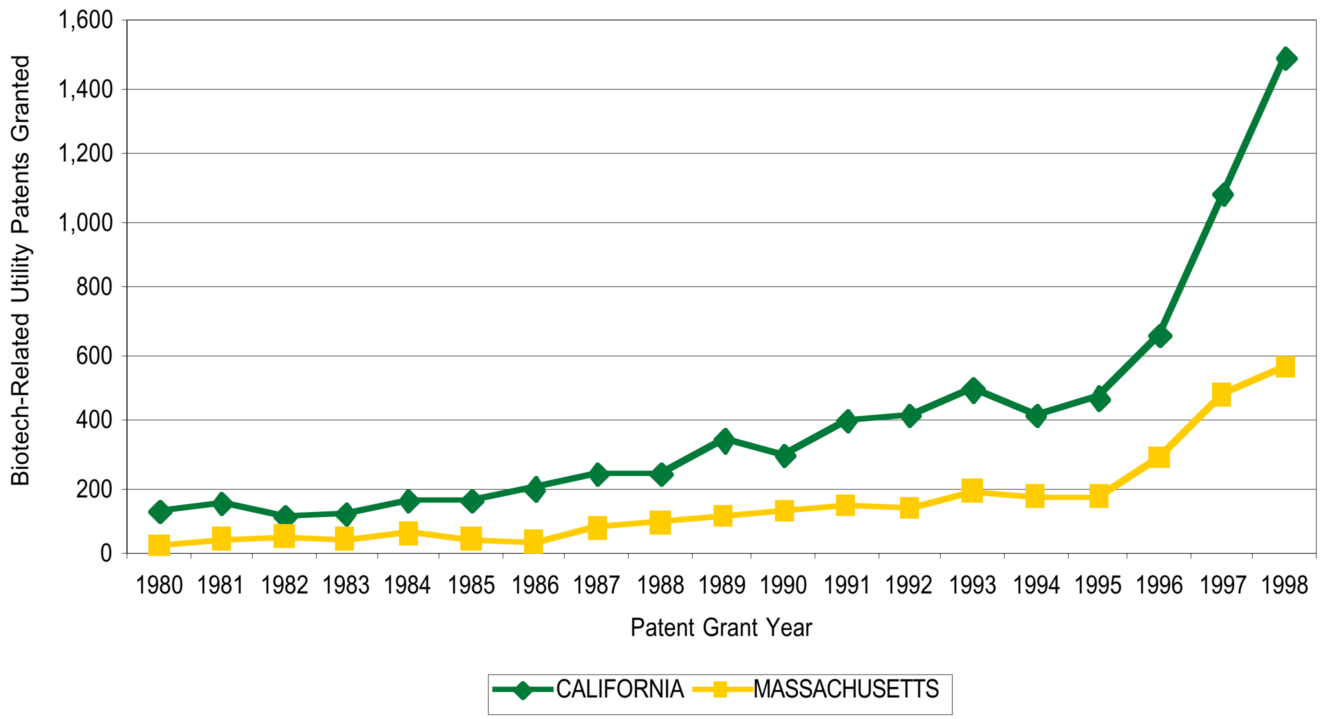

Figure 19. California vs. Massachusetts: Biotech-Related Utility Patents Granted, 1980-1998

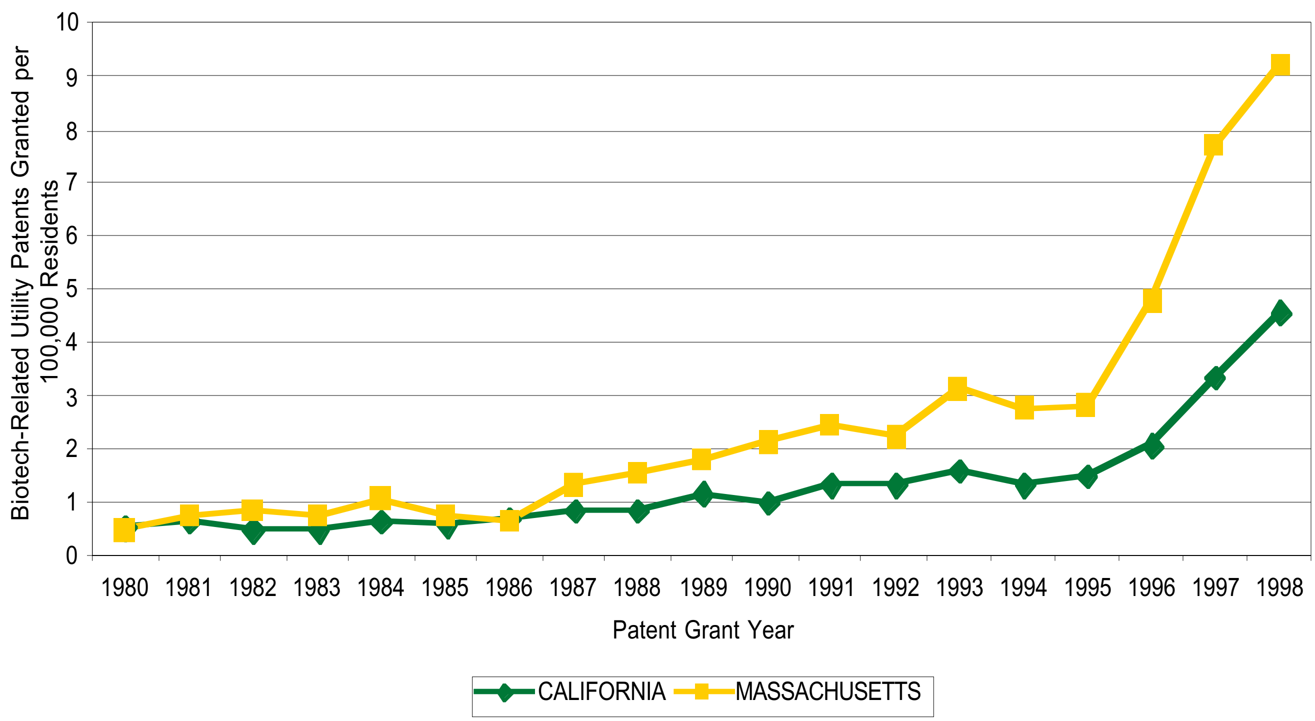

Figure 20. California vs. Massachusetts: Biotech-Related Utility Patents Granted per 100,000 Residents, 1980-1998

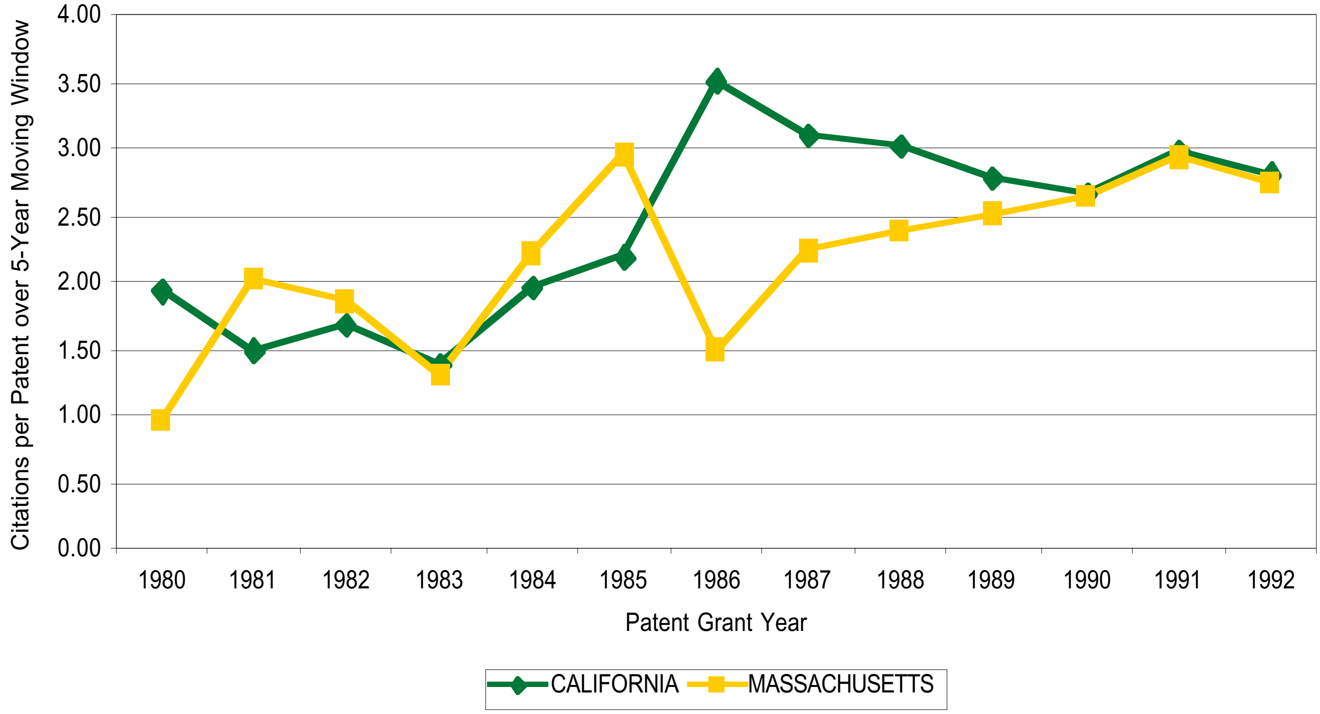

Figure 21. California vs. Massachusetts: Patent Quality, Citations per Biotech-Related Patent over 5-Year Moving Window, 1980-1992

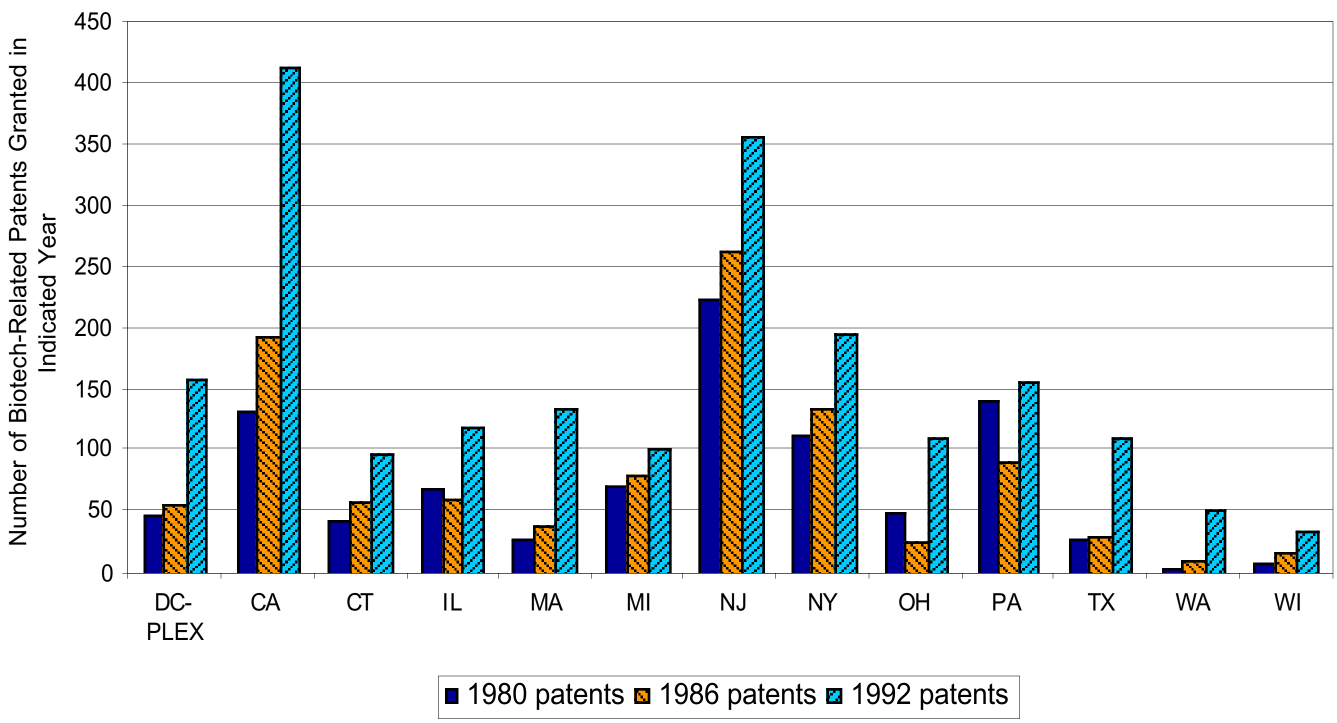

Figure 22. Biotech-Related Utility Patents Granted to Inventors in High-tech States: 1980, 1986 and 1992

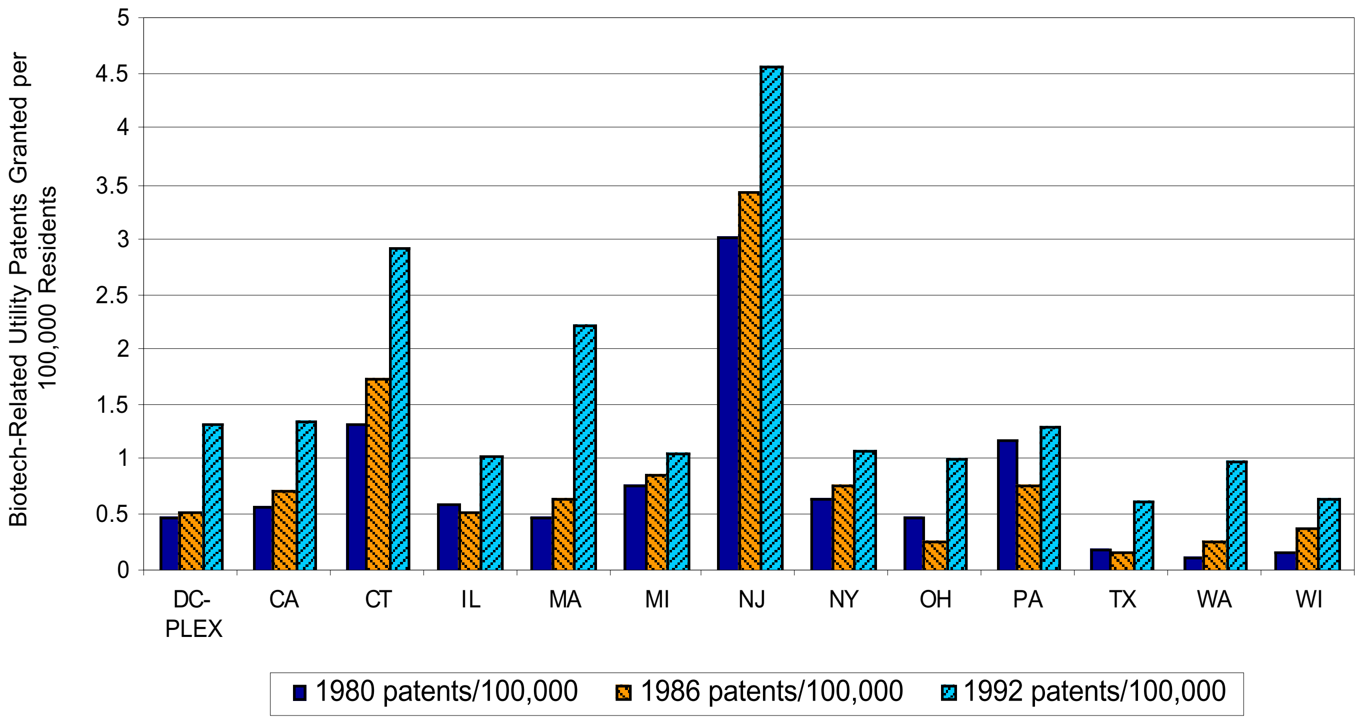

Figure 23. Biotech-Related Utility Patents Granted per 100,000 Residents: High-tech States, 1980, 1986 and 1992

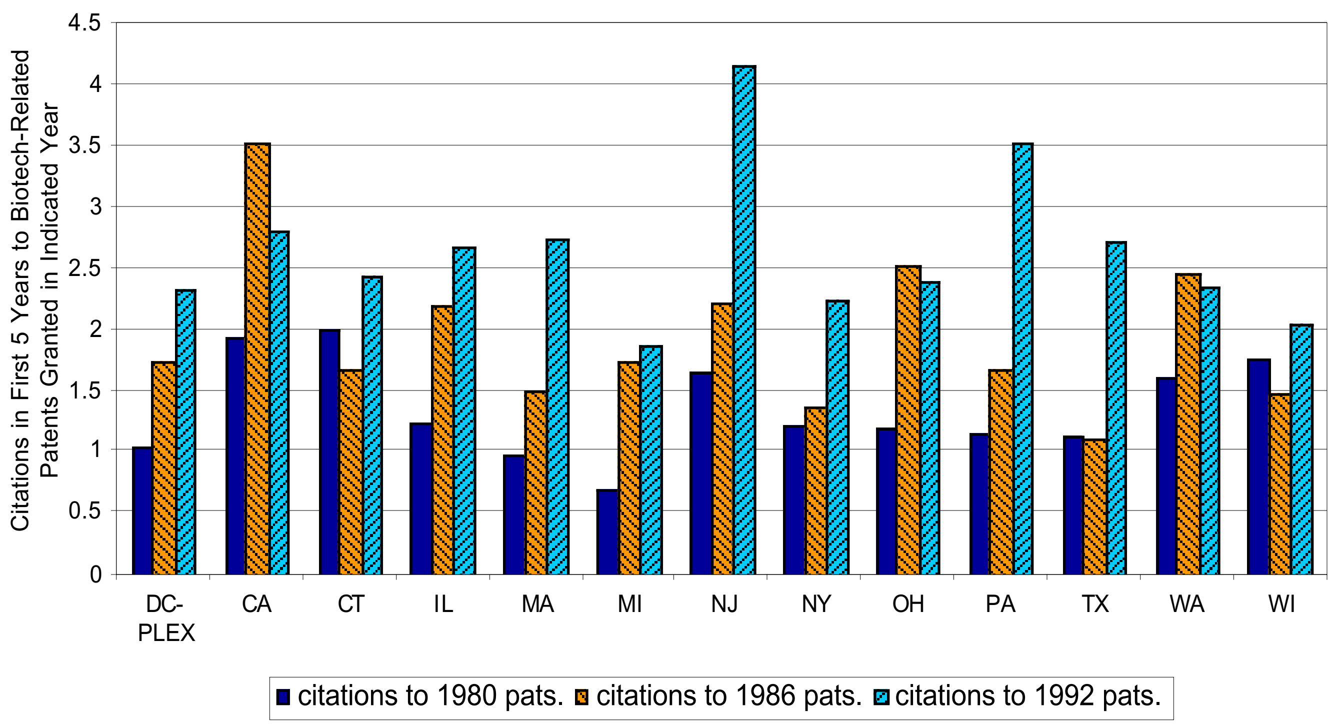

Figure 24. Biotech-Related Patent Quality, High-tech States: 1980, 1986 and 1992

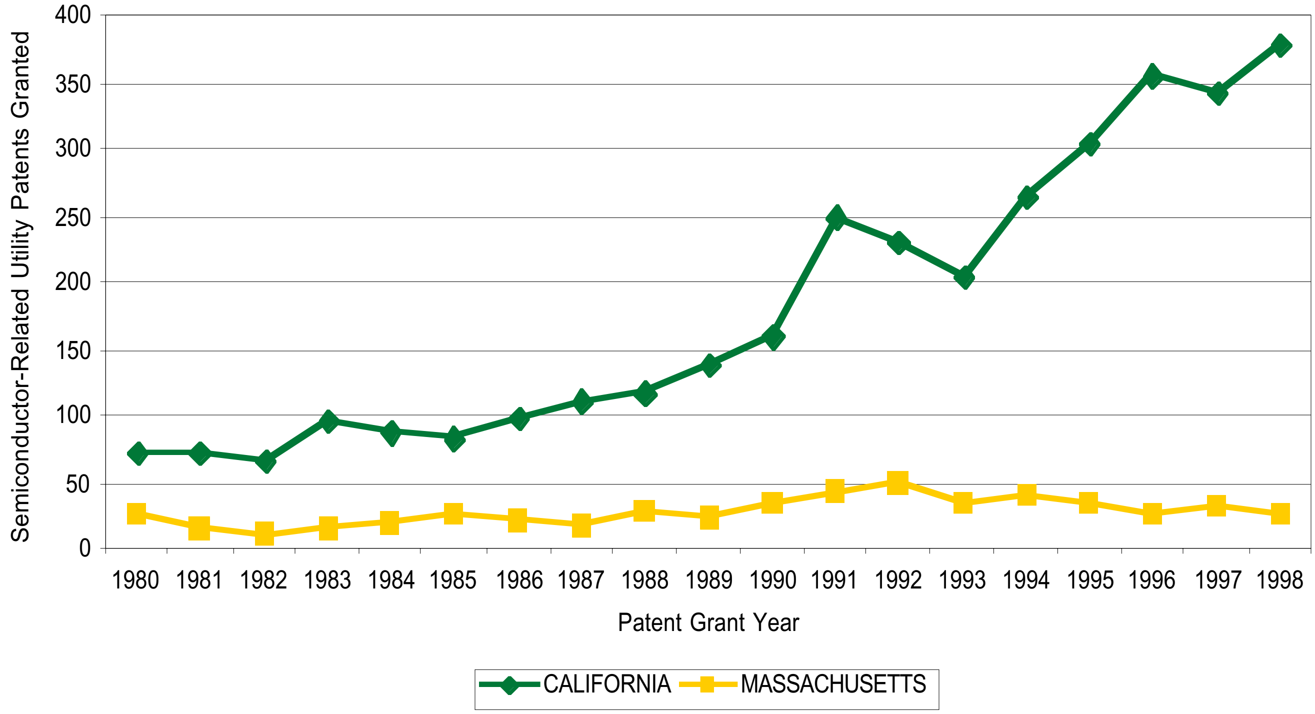

Figure 25. California vs. Massachusetts: Semiconductor-Related Utility Patents Granted, 1980-1998

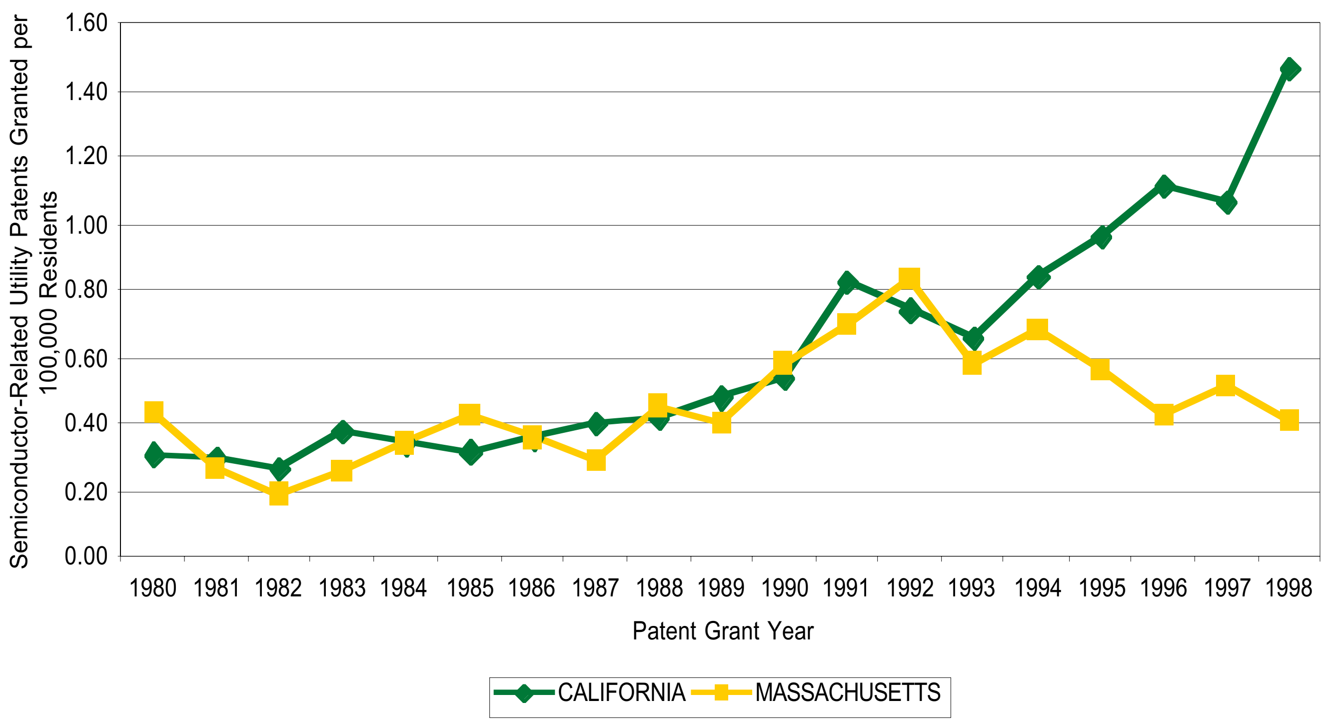

Figure 26. California vs. Massachusetts: Semiconductor-Related Utility Patents Granted per 100,000 Residents, 1980-1998

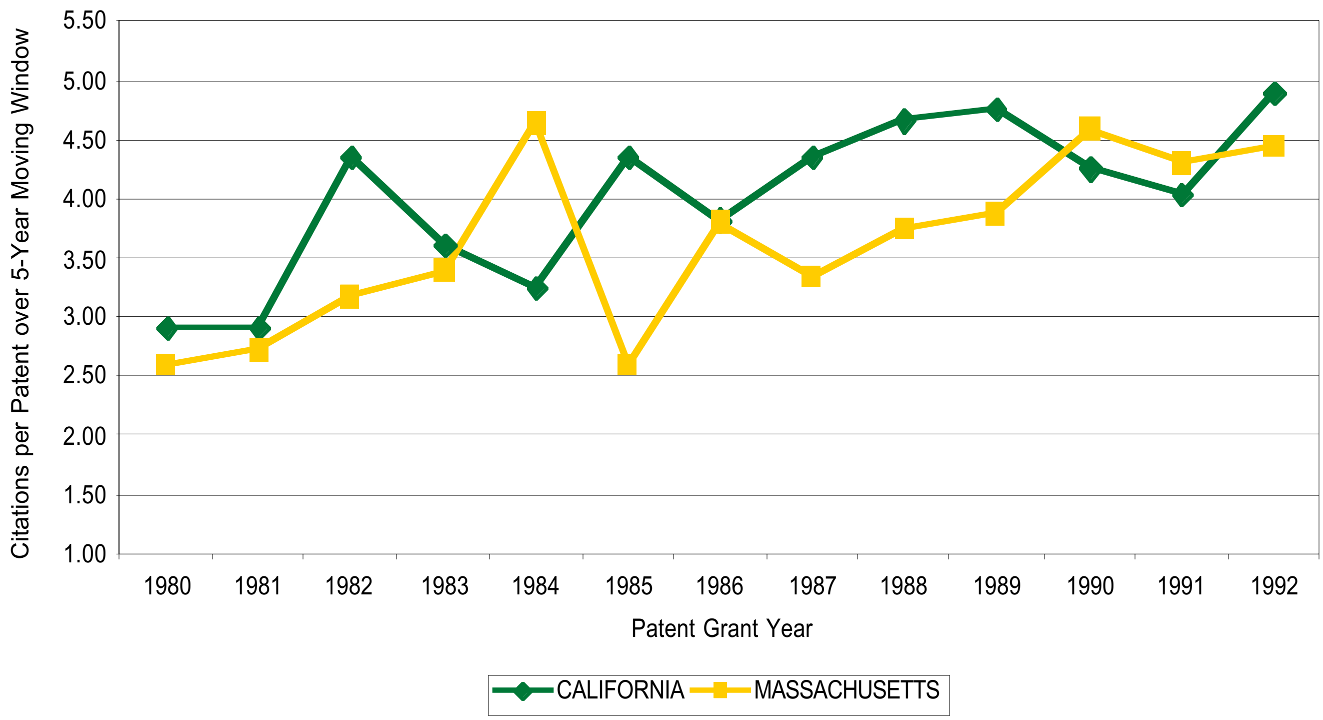

Figure 27. California vs. Massachusetts: Patent Quality, Citations per Semiconductor-Related Patent over 5-Year Moving Window, 1980-1992

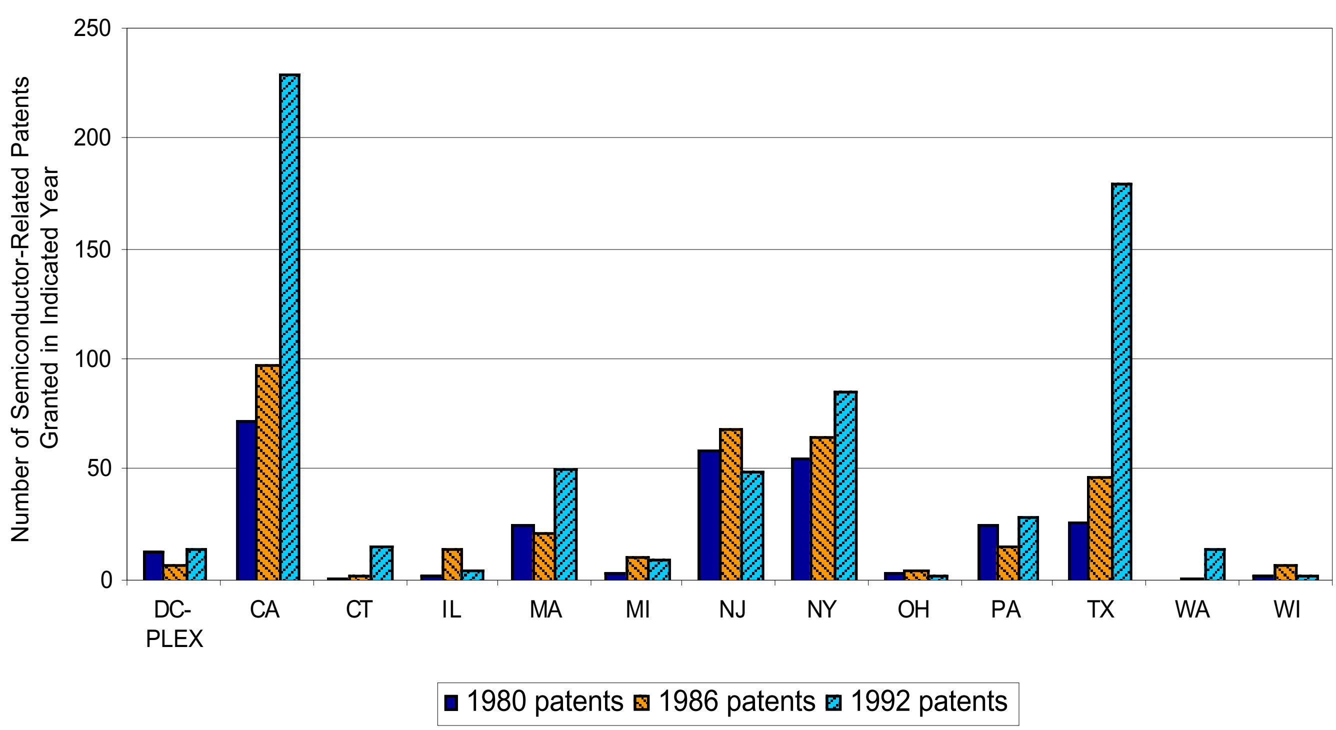

Figure 28. Semiconductor-Related Utility Patents Granted to Inventors in High-tech States: 1980, 1986 and 1992

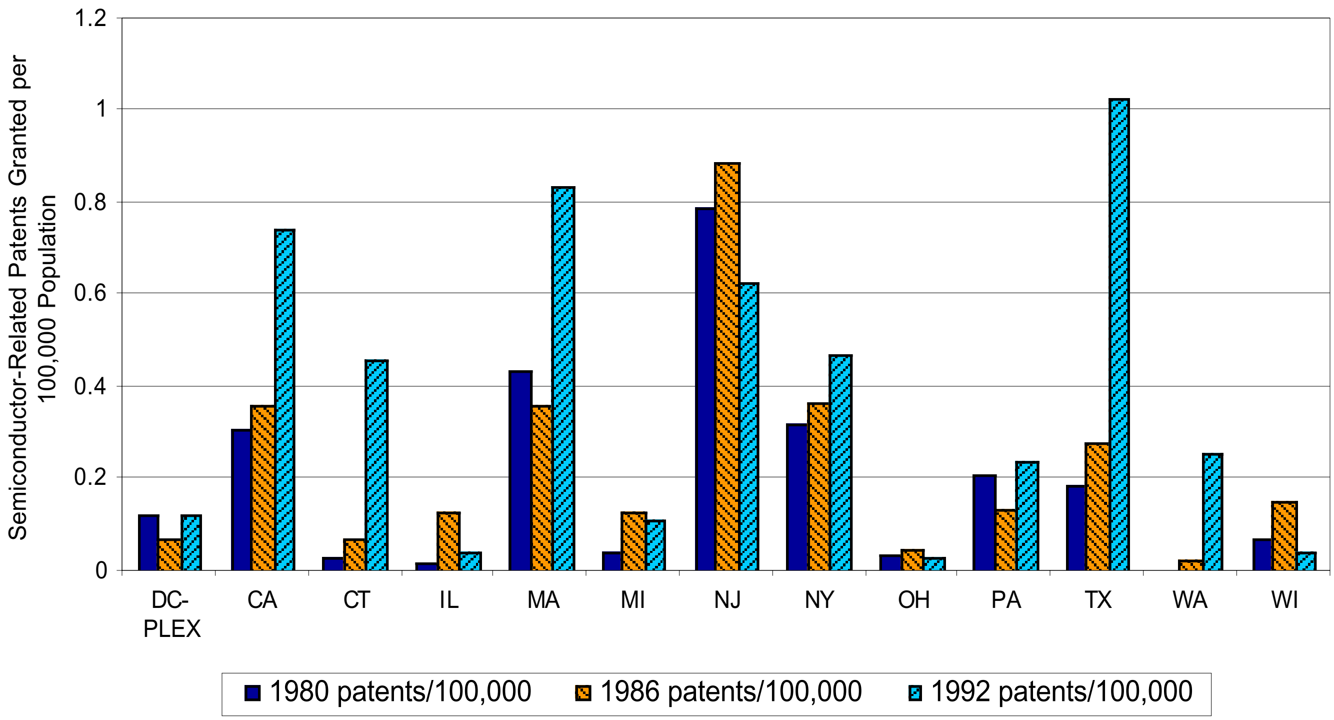

Figure 29. Semiconductor-Related Patents Granted per 100,000 Residents: High-tech States, 1980, 1986 and 1992

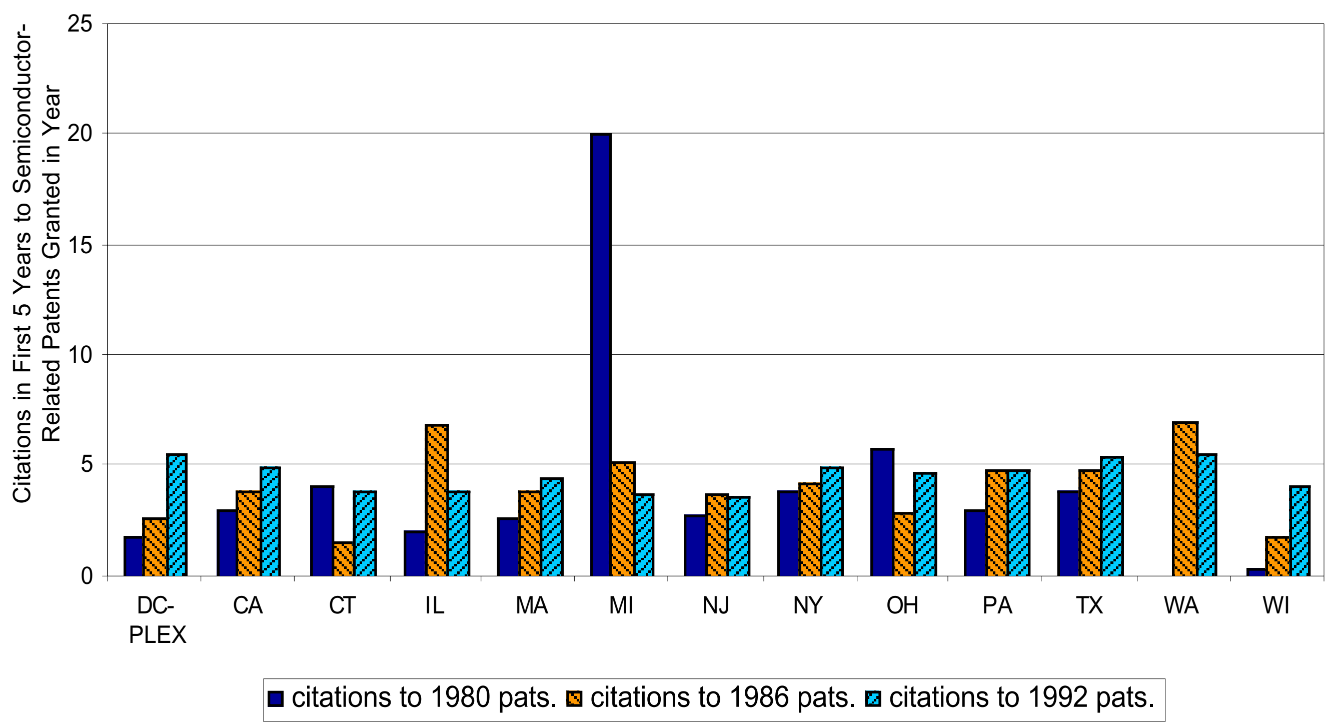

Figure 30. Semiconductor-Related Patent Quality, High-tech States: 1980, 1986 and 1992

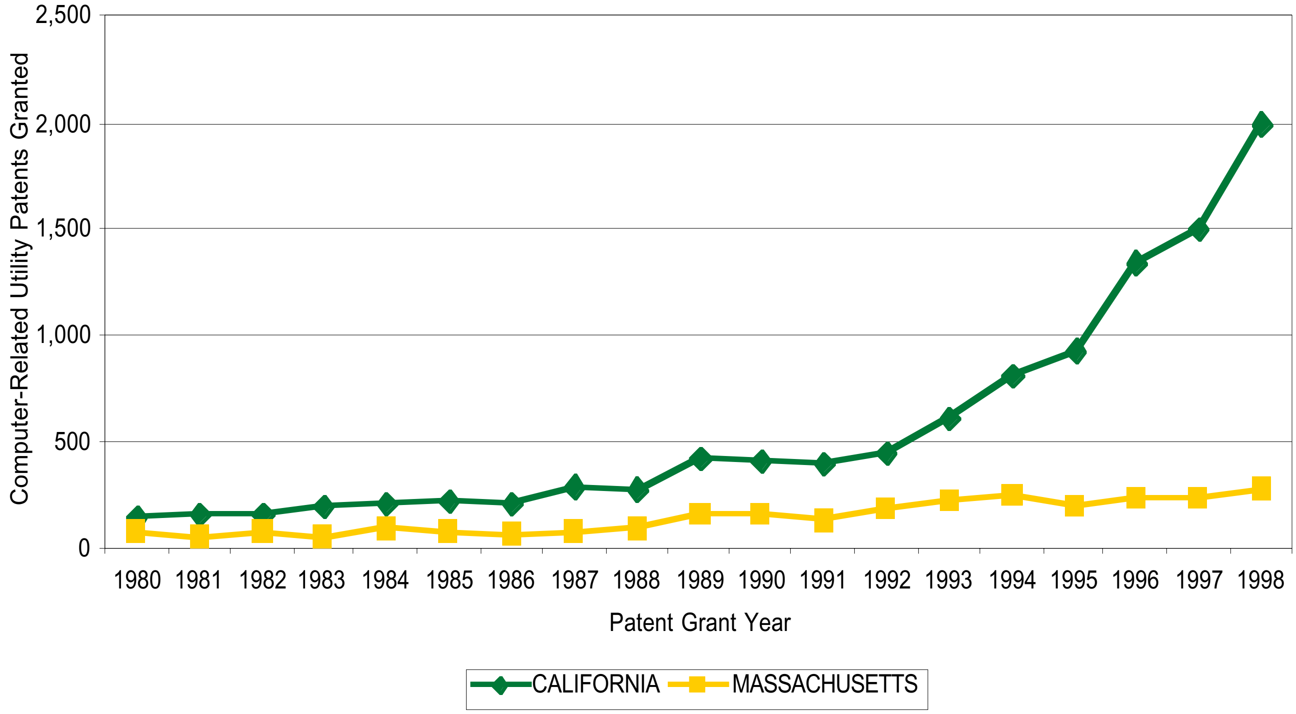

Figure 31. California vs. Massachusetts: Computer-Related Utility Patents Granted, 1980-1998

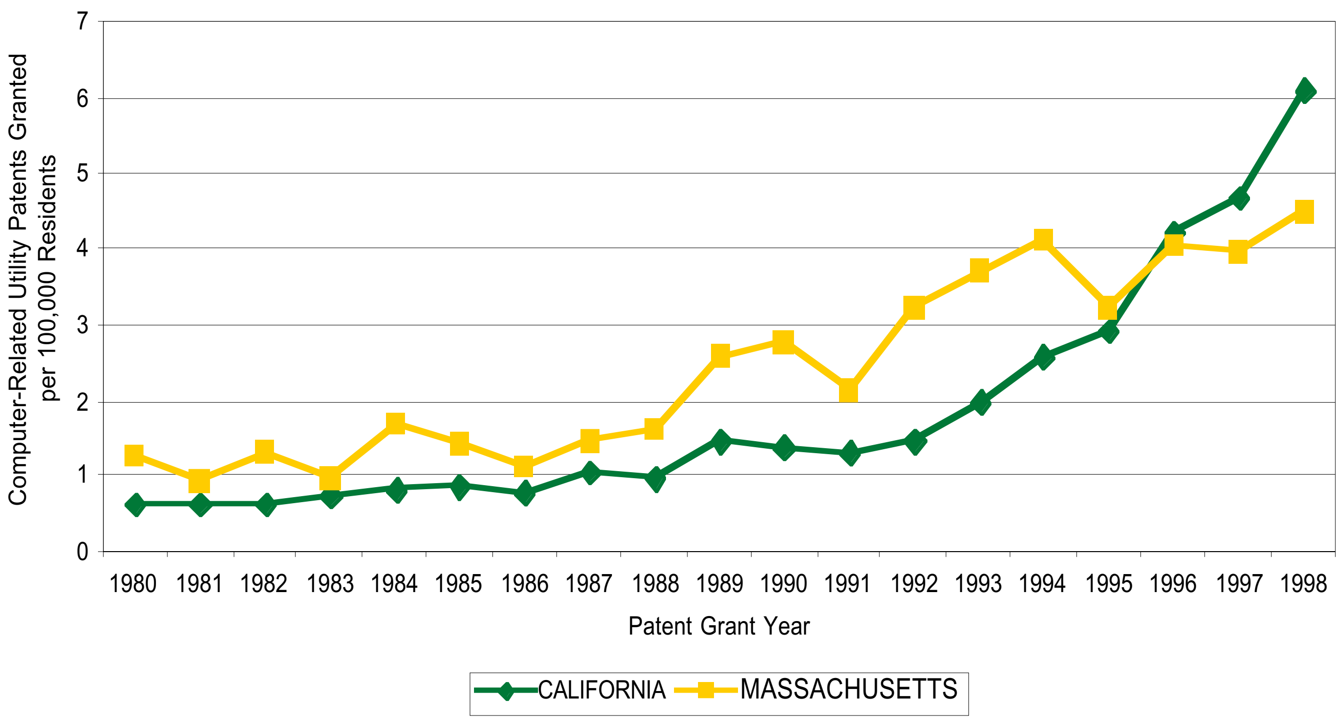

Figure 32. California vs. Massachusetts: Computer-Related Utility Patents Granted per 100,000 Residents, 1980-1998

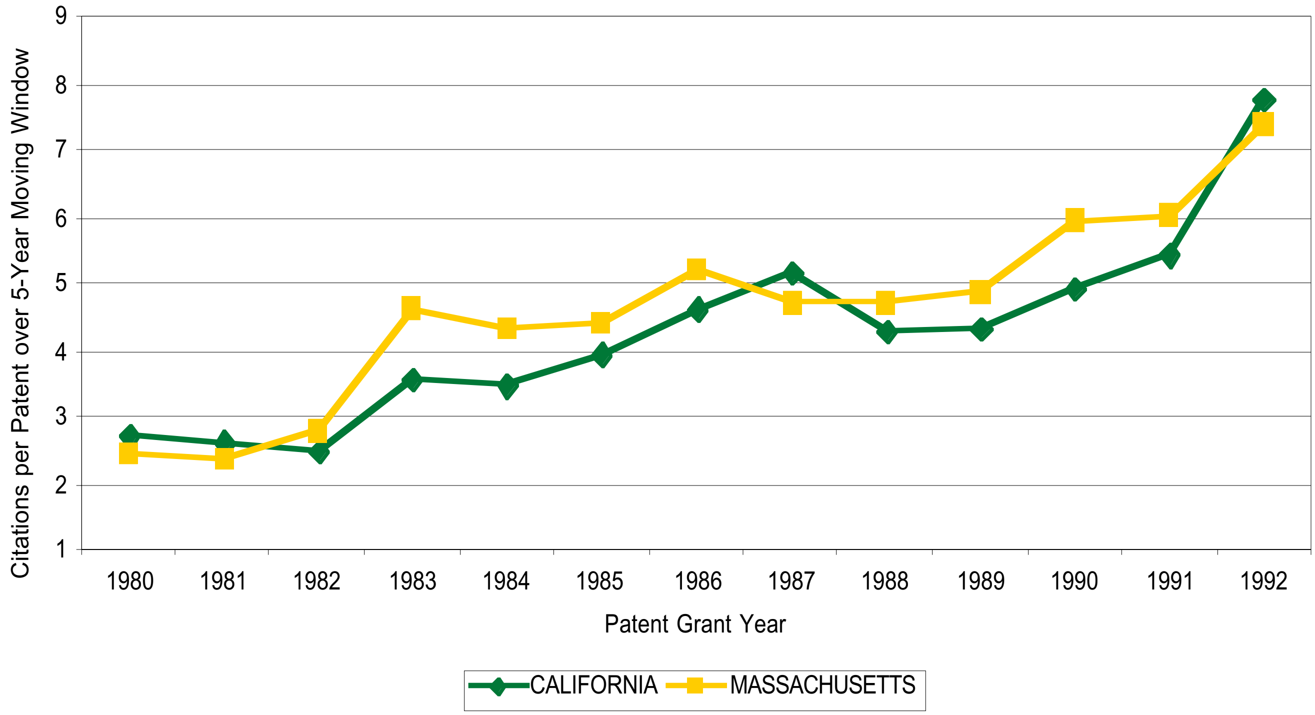

Figure 33. California vs. Massachusetts: Patent Quality, Citations per Computer-Related Patent over 5-Year Moving Window, 1980-1992

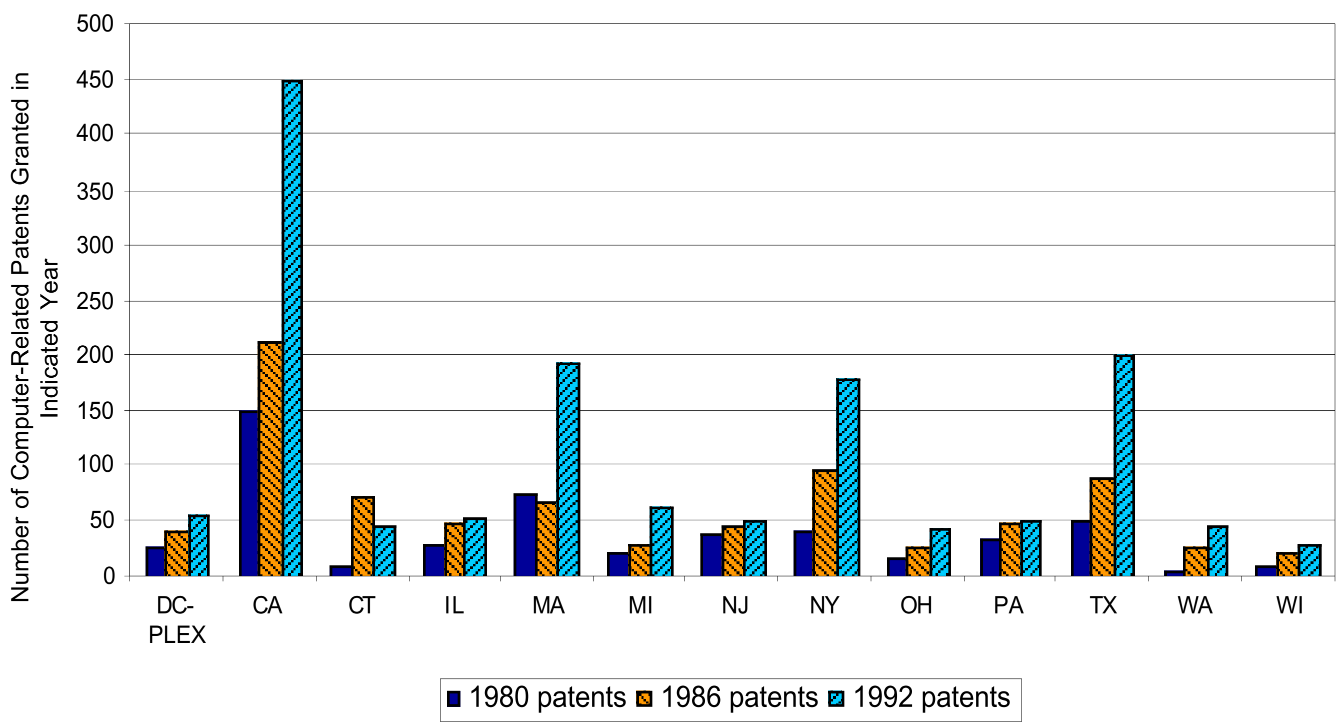

Figure 34. Computer-Related Utility Patents Granted to Inventors in High-tech States: 1980, 1986 and 1992

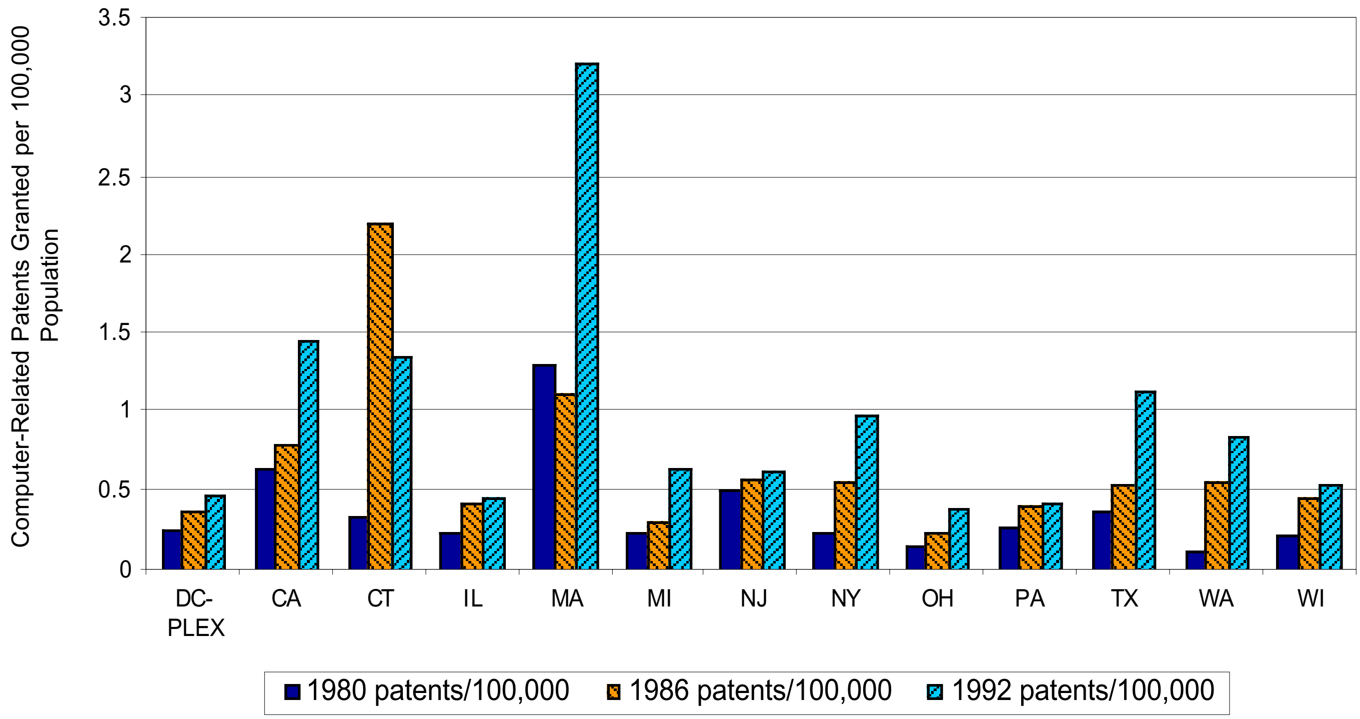

Figure 35. Computer-Related Patents Granted per 100,000 Residents: High-tech States, 1980, 1986 and 1992

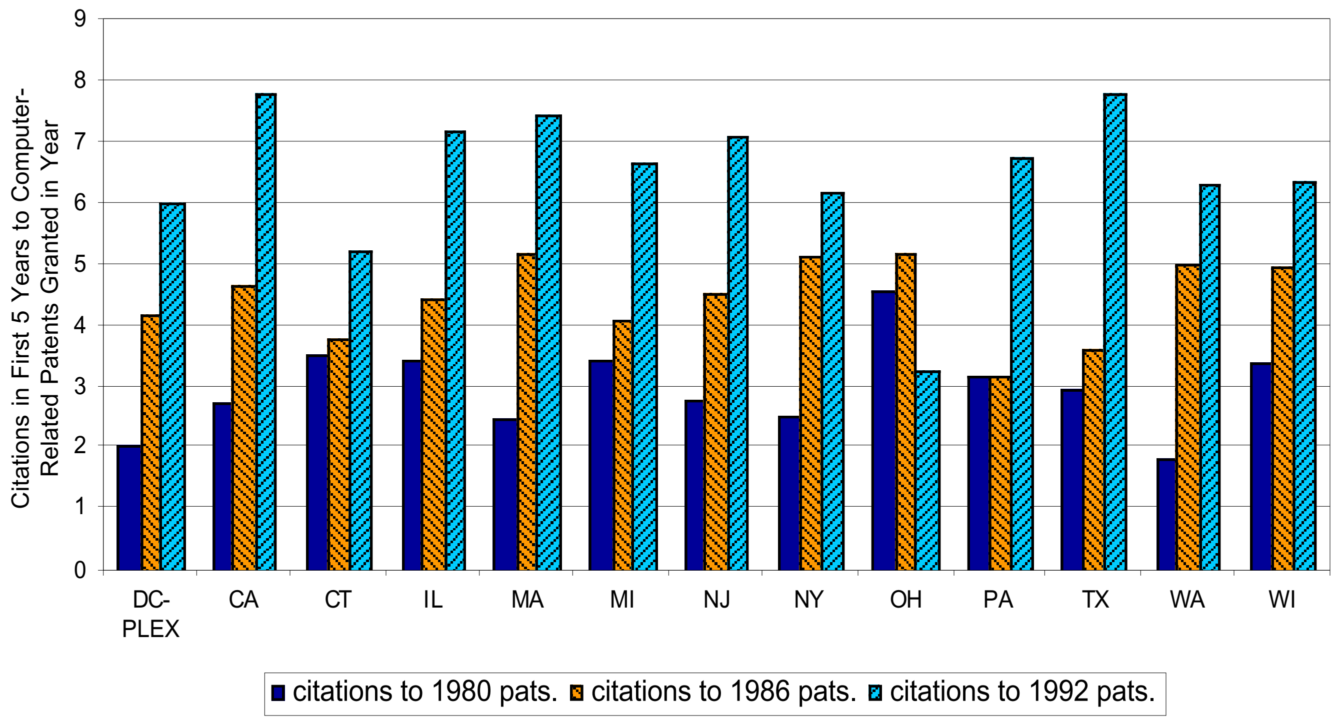

Figure 36. Computer-Related Patent Quality: High-tech States, 1980, 1986 and 1992

6. Appendix

6.1. Location of Inventive Activity and its Commercialization

We determine location by the address of the first inventor, not by location of the assignee. About one-quarter of all patents do not have assignees; assignees are typically the organization that will be doing the work to commercialize the invention, often the employer of the inventor(s). Assignee and first inventor may or may not be in the same geographic area, but the headquarter location of the assignee is commonly used in filing the patent application and thus for large organizations with multiple business units that address may not be related to the location of the commercial activity. Hence, it is not easy to determine whether the actual location of the commercial activity is likely to be closer to the first inventor (or to another one of the listed inventors) or to the assignee.

To the degree inventors are providing intellectual capital to assignees in other states, the main economic benefits may not lie in the inventor's state but in the assignee's state. The NBER data set that we used for the analyses reported here does not geo-code the assignee.

6.2. Geographical Categorization

The District of Columbia, Maryland and Virginia together are aggregated into a single region called DC-plex, which this presentation considers a state for the sake of convenience. As a result, DC-plex and each state of the rest of the United States are the unit of analysis of this presentation. We also have sums or statistics at the two aggregate levels: national and high-tech states, which, in this presentation, are California, Connecticut, DC-plex, Illinois, Massachusetts, Michigan, New Jersey, New York, Ohio, Pennsylvania, Texas, Washington, and Wisconsin.

6.3. Time Variable

Tables on number of patents report the actual number granted in the year indicated; there is a variable amount of time between patent application and patent granting, but the NBER data set we used for all analyses does not report the full date of application. Hence patent grant date is our variable for all tables.

All data on patent citations is in a time-series format where the year indicates the start of a five-year moving window, ranging from 1980 through 1996. Thus, for instance, citations labeled '1980' actually are the combined citations of 1980, 1981, 1982, 1983, and 1984 to patents issued in 1980. We use only a five year moving window since "early citations" (made shortly after the patent is granted) are both sparse and not good predictors of eventual citation.

6.4. Patent to Industry "Mapping"

Information that locates high-technology patents among the broad patent classes used by the U.S. Department of Commerce Patent and Trademark Office (1993) comes from two sources. Our biotechnology patent classes are identified in the Patent Technology Set for Genetic Engineering (cd-rom produced by USPTO), augmented by separate analyses of USPTO patent classes. Semiconductor-related and computer-related classifications come solely from separate analyses of US patent classes. CHI Corporation aided in development of these three main classes.

Table A.1 presents the definitions used for technology areas of patenting and the numbers of patents found in each broad area.

Table A.1. Industry Mapping by Patent Class[a]

Technology Area	Patent Classes	Total # 1981-90
Biotechnology	435, 424, 514	14,998
Semiconductor	437, 257	4,263
Computer	395, 364, 360	11,236

[a]We omit partial classes, and select the "pure" industry classes for simplicity in our presentation.

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