Interregional and Interurban Convergence in Knowledge Production?: Spatio-Temporal Changes in U.S. Patenting, 1965–1997

Sonn, Jung Won*
*Department of Geography and Environment
London School of Economics
Houghton Street London WC2A 2AE. U.K.
Email: j.sonn@lse.ac.uk

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ABSTRACT
Recently, ample evidence has been found that innovations are still highly clustered in a small number of places, mostly in the largest metropolitan areas. However, few have attempted to illuminate historical changes in the degree of clustering. Based on patent records in the US, this paper tests whether there are interurban and interregional convergences. I found evidence that interregional convergence is limited and there is a new core emerging in the West. I also found evidence that the largest metropolitan areas are still the most innovative places and thus interurban convergence has been very limited.

1. Introduction

It has long been hypothesized that improvement in transportation and telecommunications would create a world in which everything is dispersed (McLuhan, 1964; Naisbitt and Aburdene, 1991; Negroponte, 1995; Pascal, 1987; Virilio, 1993). According to this hypothesis, the development of new technology, or knowledge production, which does not require a heavy infrastructure or a large labor supply, should be more dispersed across space than most other human activities. Against this hypothesis, some urban economists and economic geographers argue that knowledge production is actually highly clustered in a small number of places (Acs, 2002; Audretsch and Feldman, 1996; Feldman and Florida, 1994; Storper, 1997). The latter standpoint seems to have led most geographers and urban economists to reject the dispersion hypothesis.

A closer examination of the literature, however, shows that a methodological discrepancy across the literature prevents both the ultimate acceptance and the complete nullification of the dispersion hypothesis. Firstly, most of the existing studies on clustering use a dataset that covers one point in time and are thus unable to determine whether the present clustering is a mere residue of past clustering that will eventually fade away or a live phenomenon that is still continuing to be actively reproduced. Secondly, the convergence argument is mainly based on state or regional scale analysis, while the clustering argument is based on urban or local scale analysis.

This paper attempts to address these methodological issues and to contribute to the convergence vs. clustering debate. More specifically, these

tasks are accomplished by 1) employing time series data and focusing on temporal changes in analyses. 2) distinguishing two scales, i.e. the interregional and the interurban, and conducting analyses at both levels.

In addition to its main purpose, this paper intends to lay some foundations for further geographical research on patenting. Patent data are increasingly used as a measure of knowledge production. Thus, they attract the attention of many disciplines. Economic geographers are quickly catching up, but a comprehensive profile of patent data does not yet exist. By providing a more comprehensive description of the geography of patenting in the U.S., this paper attempts to stimulate further research on the geography of knowledge production.

2. Convergence and Divergence in Knowledge Production

2.1. The Neoclassical Approach to the Location of Knowledge Production

The dispersion argument, as cited above, is consistent with the predictions of neoclassical approaches to industrial location research. The neoclassical approach assumes that both employers and workers will move around in search of higher return. R&D workers, mainly composed of scientists and engineers, will move to regions where knowledge production labor is scarce and thus better compensated. R&D employers will move to regions where R&D firms are scarce. In this way, they can price their products (new ideas) higher and pay their employees less. Through this relocation process, regions,

in spite of their different starting points, would look similar in the end. If this theory holds true, today's clustering of knowledge production should be a residue of past clustering. Of course, changes in technology, industrial structure and other factors delay, interrupt and even temporarily reverse this convergence, but at the very least, this convergence should still be an observable tendency.

A number of empirical studies have found some evidence that convergence in patenting is actually taking place. Lamoreaux and Sokoloff (1999), based on their analysis of 19^{th}-century patent records, found that knowledge production was diffused from the New England, Mid-Atlantic and East North Central regions to other regions. Varga (1999) also finds convergence in patenting. According to his analysis, the traditional patenting leaders, the Northeast and the Midwest grew by only 45% and 53% respectively, while the traditionally lagging West and South grew by 128% and 79% respectively. Co (2002) also found that the lagging states were catching up. She attributes this catch-up to income convergence, convergence in knowledge production spending, convergence in the quality of infrastructure and labor quality.

2.2. Divergence Theories

The neoclassical location theory is hardly the mainstream view in contemporary economic geography, in spite of its alliance with neoclassical economics. The overwhelming majority of industrial location theories predict continued reproduction of the clusters of knowledge production. Although

few theories have been devised specifically in order to explain the location of knowledge production, logical extensions of many theories, including Hägerstrand's (1952) theory of innovation diffusion, Myrdal's (1958) "cumulative causation" theory, Vernon's (1966) "product lifecycle" theory, Hoover and Vernon's (1962) "metropolitan incubator" theory and, more recently, Krugman's (1991; 1995) "New Economic Geography", would all predict that the existing cores of knowledge production will continue to be the cores. I would refer to this group of theories collectively as the "divergence theory of knowledge production".

The oldest of all divergence theories stems from Hägerstrand's model of "hierarchical effect" (Hägerstrand, 1952). The hierarchical effect refers to the process whereby innovation diffuses from a large city down through an urban hierarchy to smaller cities. Under this model, innovative activities, including knowledge production, should be conducted in the largest metropolitan areas. Other cities should then merely adopt such innovations.

Similar to the hierarchical effect model but more specifically pertaining to economic phenomena are the product lifecycle theory and the metropolitan incubator theory. In the product lifecycle model suggested by Vernon (1966) and Norton and Rees (1979), new products are usually developed and produced in an urban center, because their inventors have better access there to information on consumers' needs. As the technology matures and become standardized and demand becomes stabilized, production can move to suburban and rural areas and developing countries, where cheaper labor and

land are available. A new round of innovation, then, again occurs in urban centers for the reasons stated above. This process is repeated and thus urban centers continue to be the place where innovations take place. Therefore, knowledge production will always be in urban centers.

The metropolitan incubator theory, a widely used theory in urban economic development, draws a similar conclusion (Hoover and Vernon 1962). This theory argues that metropolitan centers play the role of incubator for newly-born innovative firms by providing them with access to technological knowledge, a marketplace for experimental products and producer services (such as legal, accounting and marketing services) that a new firm cannot afford in-house. The urban incubator hypotheses, therefore, predicts the same geographical pattern of knowledge production as the product lifecycle theory does.

Gunnar Myrdal (1958) would also have predicted the persisting dominance of existing cores if he had applied his concept of "circular cumulative causation" to the geography of knowledge production. A center of knowledge production will attract talented researchers from other locations because the return to a unit-research labor will be greater at well-established cores of knowledge production, where a talented researcher can be teamed up with other talented researchers and where they can collectively have access to better facilities. Knowledge production capital would also prefer established-knowledge production centers because, thanks to their pool of talented people and facilities, the return to marginal investment is greater there.

Similarly, when the two main concepts of the New Economic Geography, "increasing return to scale" and "transportation cost," are applied to the issue of knowledge production, one would also predict the continued clustering of knowledge production. First, because the transportation cost of knowledge is not zero, it is better to produce knowledge where the market for such knowledge is greatest. And if the production of knowledge is the same as the production of material goods, this would yield an increasing return to scale. This means that the place that with a head start in a certain kind of knowledge production and achieved a bigger scale would continue to lead its later and smaller competitors. This reasoning would not apply if the transportation cost for knowledge was zero. But, in the majority of cases, transportation of knowledge does have a cost. The cost of sending scientific papers or blue prints by mail or email is almost negligible these days, but quite often sending information does not suffice. Face-to-face contacts are required when complicated new ideas are transferred or mutual trust is required (Storper and Venables 2004). And travel still has both monetary costs and cost in terms of time and physical fatigue. Therefore, the transportation cost of knowledge cannot be assumed to be zero.

If these divergence theories explained above are correct, the traditional cores of innovation in the U.S. (i.e., the Northeast and the Midwest at the interregional level and the largest cities at the interurban level) should continue to be the leaders in knowledge production. Some evidence to support this standpoint was found.

Aharonson, Baum and Feldman (2004) found that firms in clusters are eight times more innovative than dispersed firms. Baptista and Swann (1998) tested whether firms in well-developed industrial clusters innovate more actively. They found a positive correlation between a firm's innovativeness and the same industrial sector's regional employment. Oakey, Thwaites and Nash (1980) argued that the South East region, which is the U.K.'s traditional core of knowledge production, is more innovative than other parts of the U.K.

Some authors specifically consider city size as a determinant of the efficiency of knowledge production. Moomaw (1981) estimated the productivity of cities and found that larger cities have higher productivity than smaller cities. Similarly, O'hUallachain (1999) found a positive correlation between city size and number of patents per worker.

2.3. Methodological Issues in the Existing Literature

Both the convergence theory and the divergence theory have relatively coherent theoretical explanations and have accumulated some empirical evidences. This apparent contradiction cannot be resolved within the existing literature due to methodological issues.

First of all, not all studies have used time-series data in their analysis. As previously mentioned, most of the studies cited in support of divergence are based on an analysis of panel data. Therefore, even if they find evidence of the clusters' existence, they can not completely reject the dispersion hypothesis because the opponent would state that the degree of concentration has been decreasing and the clusters would soon fade away.

Secondly, the geographical scale of analysis is not consistent across the existing literature. While much of the convergence argument finds its support in the evidence of interregional convergence, the divergence argument is based primarily on findings that leading cities in knowledge production continue to be leading cities, i.e. interurban divergence. This difference in geographical scale of analysis prevents the comparison of the findings from two separate lines of research because, in theory, convergence at one level does not automatically accompany convergence at another level. When knowledge production activities are relocated from the biggest cities in an advanced region to the biggest cities in an underdeveloped region, what we will see is an interregional convergence without interurban convergence. On the other hand, if knowledge production activities are relocated from the largest cities to smaller cities within an advanced region, we do have interurban convergence but we do not have interregional convergence. Therefore, it is necessary to distinguish two different scales.

In this context, this paper intends to contribute to the convergence vs. divergence dispute by responding to these two methodological problems. Firstly, this paper employs time-series data to capture temporal changes. Secondly, two different scales are used to separately cover the issues of interregional convergence and interurban convergence. Further details of the methodology used are explained in the next section.

3. Patent Data and its Exploratory Analysis

3.1. Patent Data as a Measure of Knowledge Production

This research uses patent records as the measure of knowledge production. Of course, there are numerous other measures of knowledge production than patent records. The number of R&D labs, the number of R&D employees and R&D investment are three of the most common measures. The innate problems associated with these measures, however, are causing an increasing number of scholars to use patent as their knowledge production measure.

First of all, the number of R&D laboratories or R&D employment do not account for knowledge production outside formal R&D labs. Small- and medium-sized firms oftentimes cannot afford formal R&D labs and thus conduct their research on the shop floor. There are also independent inventors whose output sometimes has a considerable impact. A better alternative might be to actually count the number of innovation incidents by surveying primary and/or secondary sources. But a critical weakness of these survey data is that, because of their high costs, the surveys are not repeated in the same format and thus do not provide time-series information.

Patent data substantially overcome the weakness of surveys. Patent records have been kept by the USPTO since 1790, when the US patent laws were enacted by Congress as part of the Constitution. More than two centuries of data are currently available for time-series analysis. This gives patent data a tremendous advantage over other measures of knowledge production. Furthermore, a patent record contains the addresses of both its inventors and

its legal owners. This address information can be used for various kinds of geographical analysis.

One common reservation concerning patent data is that patented technology is not necessarily commercialized (Feldman, 1994). In other words, many patented items remain on paper and have had little economic effect. This apparent weakness turns out to be an advantage in some cases. When the issue is the production of knowledge itself, rather than its direct effects on the economy, even inventions that have not been commercialized should not be overlooked. These may later inspire directly or indirectly, inventions of commercial value, either directly or indirectly.

Another well-acknowledged weakness of patent data is that there is much knowledge production that cannot be patented. It is known that knowledge production by a big firm is more likely to be patented than that by a small firm. It is also reported that a process innovation is less likely to be patented than a product innovation. Therefore one cannot assume that patent data capture every kind of knowledge production equally. This is probably the most critical weakness of the patent as a measure of knowledge production. Fortunately, it has been found by Acs et al. (2002) that, in spite of the imperfections of the patent data, the location of patents is analogous to the location of commercial innovations, thereby permitting the possibility of using patents as a proxy for commercial innovations.

3.2. Data for this Research

Due to the advantages of patent data explained in Section 3.1, in this paper, I use patent data to explore the changing geography of knowledge production in the U.S. The patent data in this paper are taken from the National Bureau of Economic Research (NBER)'s Patent Citations Data Files (Hall, et al., 2001). The NBER patent data covers approximately three million U.S. utility patents granted between January 1, 1963 and December 30, 1999. These data streams represent the complete set of "utility patents" that were granted by the USPTO during this period. A "utility patent" is one of the five patent classes[1], granted for new and useful improvements, processes or machines. The overwhelming majority of patents issued are found in this category. I occasionally refer to patent data for the years prior to 1963. Those data are taken from Johnson and Brown (2004).

In the analysis that follows, patents are dated, whenever possible, by their year of application. On average the patent review process takes about two years, but this timeframe can be highly variable. For this reason, patent grant dates are less reliable indices of an invention's timing (Hall et al., 2001). The time-lag that exists between an invention and its patent application is believed to be relatively small because the incentive to patent quickly is generally high. Thus, a patent's application year serves as a more useful proxy for the date of invention than the grant year.

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[1] The other four are utility, reissue, design plant and statutory invention registrations.

In the cases where I was not able to use the application year for any given reason, I used the grant year instead. The number of granted patents and the number of applications has been moving in tandem during the greater part of U.S. patenting history, with the exception of a two- to four-year time-lag between the former and the latter (See Figure 1 in Griliches, 1990: 1664). Therefore, for the purposes of studying long-term trends, the grant year serves almost as well as the application year. Of course, for the previously stated reasons, I refrain from using the grant year when studying patents over the short term.

The geographic units of analysis employed in this paper are the state for interregional analysis and the metropolitan area (the Metropolitan Statistical Areas (MSA) or the Consolidated Metropolitan Statistical Areas (CMSA)) for interurban analysis. My analysis at the state level focuses on patents in the 48 contiguous states of the U.S. and covers the years 1964 to 1997.

While state information is available for all U.S. patents in the NBER Patent Citation Data Files, city information is available only for patents granted after January 1, 1975, which limits the analysis at interurban level to a focus on patents of which application years are later than 1974. Also, city names were used to connect patents to metropolitan areas. I assign city names with MSAs or CMSAs using ZIPList5.[2] The MSA boundaries used were the ones published by the U.S. Census Bureau in 1993.

[2] See its website (https://www.zipinfo.com/) for the details of ZipList5.

While I used the total number of patents to analyze the quantity of knowledge production in states or cities, I used the number of patents per 1,000 workers to illuminate how innovative a city's or state's economic activities are. I denote innovativeness as "density of knowledge production". Data for the number of workers by county were acquired from each year's County Business Patterns, published by the Census Bureau.

3.3. Some Background Information about U.S. Patenting

For background, it is useful to note that the number of utility patents granted in the US has increased markedly throughout the twentieth century, from a total (foreign and domestic combined) of approximately 24,000 in 1900 to about 137,000 by the mid-1990s (see Figure 2). Patents granted to US inventors increased by more than 200% over this period, while patents granted to foreign applicants increased even more rapidly, especially from the early 1960s onwards. The rising number of foreign patent applications is a reflection of globalization and, more particularly, of the recent integration of research and development activities across a number of countries (Kortum and Lerner, 1997).

The pace of growth of patenting has been uneven over time. After rising relatively rapidly between 1900 and 1910, the number of patents granted in the US thereafter increased relatively slowly until 1950, with an annual average compound growth rate of about 0.75% (see Figure 1). While the total number of patents continued to rise after 1950, those granted to domestic concerns declined over the period 1950 to 1960, and plummeted even more quickly

between 1970 and 1980. Foreign patents increased steadily during the first three decades following the Second World War, at an annual average compound growth rate of approximately 3.2% (see Figure 2).

As Figure 2 shows, from the early 1980s onwards, the pace of patenting accelerated sharply. Between 1981 and 1995, the annual average rate of increase in domestic patents exceeded 5% and the rate of increase in foreign patents was only slightly lower. This drastic increase was mainly due to the expansion of computer/communication industries and drug/medicine industries (Hall, Jaffe and Trajtenberg, 2001).

4. The Interregional Geography of Patenting

4.1. The quantity of Knowledge Production in States

Figure 3 shows how shares in U.S. utility patents changed across the four census regions during the twentieth century. In 1900, U.S. patenting was heavily concentrated in the old industrial core. More specifically, some 83% of all U.S. patents were developed in the Snowbelt areas of the New England, the Mid-Atlantic, and the North Central census regions. More than 50% of the new patents granted in 1900 were developed in only five states: New York, Pennsylvania, Illinois, Massachusetts and Ohio (in that order). In 1950, the Snowbelt, i.e. the Midwest and the Northeast, was still responsible for the production of more than 76% of all the nation's patents. However, over the second half of the twentieth century, patenting diffused across the U.S., in a pattern that followed the southern and western movement of people, capital,

and jobs. By 1999, the Snowbelt was producing less than half the nation's patents and the West had by then become the most innovative of all, housing more than 23% of the country's new utility patents.

Thus far, it seems apparent that the states that traditionally lagged behind were catching up and that the old core states were not performing as well as they did in the past. Does this mean that interstate unevenness in patenting is waning, as Co (2002) suggests?

I measured interstate unevenness in knowledge production with the coefficient of variation (CV)[3]. As reported in Figure 4, the CV was 1.61 in 1965 and gradually decreased until around 1980, when it reached a low point of 1.85. After 1983 (CV: 1.32) or at the very latest 1990 (CV: 1.33), divergence returned. In 1996, the CV is at its highest (1.50).[4]

Observing this, I am persuaded that the old form of disparity is not simply fading away, but rather that a new form of unevenness is taking the

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[3] In measuring spatial unevenness, the coefficient of variation, or *CV*, is commonly used. The CV is defined as: $CV= S \cdot 100/ \overline{x_i}$ where S stands for the standard deviation of x_i and $\overline{x_i}$ is the average of the x_i. In this formula, the subscript i refers to spatial units over which patents are recorded. If the *CV* is high, this indicates that the distribution of patents is relatively uneven across space. A low *CV* value indicates a more uniform spatial distribution of patents. The primary advantage of the coefficient of variation as a measure of the geographical dispersion of patents is that it is a dimensionless measure and so is not influenced by the marked rise in the number of patents over time.

[4] CV drops in 1997. I chose to ignore this because 1997 data are less reliable than earlier data for the reason I stated when explaining the national trend.

place of the old. Seemingly, the more even distribution of innovative activities that occurred around 1980 was only a temporary phenomenon that happened because the new center was not yet established, while the old center had already declined.

The discrepancy between my findings and Co's (2002) argument stems from our different means of measurement. Co (2002) uses β-convergence, which finds innovative convergence if the traditional hinterland grows faster than the traditional core. This measure, however, possesses the danger of missing the emergence of a new core (Quah, 1997). When the traditional hinterland outgrows the traditional core, there is obviously β-convergence because, the hinterlands grew faster. Few, however, would call this reversion a convergence. On the other hand, CV or other measures of α-convergence simply measure the disparity itself. This simplicity limits the statistical flexibility that would broaden its applications but would certainly measure disparity itself. If a reversion occurs, CV or other measures of α-convergence would reflect this.

With the apparent emergence of the West, on the one hand, and increasing CV on the other hand, I have to conclude that the West is becoming the new core of knowledge production, at least in terms of the quantity of knowledge production.

The changing center of innovative activities is partially explained by the relocation of population, companies and jobs. The movement of people and employment opportunities away from the old industrial core to new growth

centers in the South and West was a relatively gradual shift that began around the middle of the twentieth century. But the remaining question is whether the changing geography of patenting is completely explained by the new spatial distribution of the U.S. economy.

4.2. Density of Knowledge Production in States

It turns out that job relocation does not completely explain the rise in patenting in the West and South. The South and West became more innovative at the same time as they were gaining employment share.

Figure 5 shows the ranking of states by patenting per 1000 workers in 1965 and 1997. On the 1965 map, high ranking states are concentrated in the Northeast. Exceptions, such as California and Oklahoma, do exist, but most of the states in New England and Mid West were in the top 19. By 1997, however, an equally innovative group of states exist in the West. Idaho joins the top 10 and Texas, Utah, Oregon and Portland join the top 19. This new group of innovative Western states seems just as dominant as the Northeast. The Southern states, on the other hand, still lag behind the West and the Northeast, in spite of substantial improvement.

Overall, while the landscape of patenting in 1965 exhibits a strong core, that of 1997 has two strong cores (one emerging and the other declining), with lagging states in the middle.

These findings imply two trends. First, the southern states are becoming more innovative, but they still lag behind those in the West or the Northeast. Therefore, the growth of patenting in the South can be called a partial catch-up.

Second, the emergence of the West as a knowledge production core is more than merely a matter of catch-up -- The West is at least equally innovative, and possibly more innovative, than the old core. This tendency reveals an emergence of a new core rather than a catch-up, a trend that becomes more apparent when the interstate difference is quantified. Figure 6 shows the CV of patenting per 1,000 workers by state.

This process of relocation of knowledge production created a decreasing disparity among states in the beginning. However, as the relocation increases, the disparity starts to increase. Figure 6 shows the coefficient of variation in patent per 1000 workers. The trend is similar to that of the number of patents in Figure 4. This means that, while relocation of firms was taking place, the relocation of innovative firms was even more pronounced. It is also noteworthy that divergence begins much later in Figure 6 than it does in Figure 4. This is due to the time-lag between the relocation of productive activities and that of innovative activities. The West became dominant in number of patents much before it did in patents per 1000 workers.

4.3. Two Sides of the Changes at inter-regional level: A Partial Convergence and a New Divergence

My analysis above shows that the rise in patenting in the Sunbelt stemmed both from the relocation of jobs and from the region's more innovative industries. Interregional convergence, as predicted by the neoclassical location theory, may have happened in the case of the South. On the other hand, the

growth in knowledge production in the West has been found to indicate the emergence of a new core, rather than a peripheral regional catch-up.

The rise of the West as the new core region for knowledge production is more or less apparent. In terms of the number of granted patents, states in the West (California, Texas and Arizona in particular) not only caught up with the states in the Northeast and the Midwest, but started to outperform them. This turnover is partially explained by the overall relocation of industries from the Snowbelt to the Sunbelt, but that is not all. The innovativeness of states, as measured by the number of patents per 1,000 workers, also indicates superior performance in the Sunbelt states. But, it has to be pointed that not all the Snowbelt states have been replaced by Sunbelt states and that some Snowbelt states still have a considerable share in knowledge production. The state of New York is a prominent example. This means that the some regions can readapt themselves to the new environment and retain their position in knowledge production. However, overall, it is more or less evident that the Sunbelt has become the new core region in knowledge production.

Among states traditionally lagging in knowledge production, the Southern states are catching up fast, but are still behind those in the West and in the Snowbelt. On the other hand, Intermountain states such as Wyoming, North and South Dakota and Montana do not show signs of catch-up.

5. The Interurban Geography of Patenting[5]

5.1. The Quantity of Knowledge Production in Cities

Section 4 provided evidence for the emergence of a new core region. This section continues the analysis at the interurban level. Table 1 shows the top 20 innovative metropolitan areas in each decade. To compensate for a possible yearly fluctuation, a three-year total was used rather than a single-year total. From 1974 to 1977, of the top 20 most innovative metropolitan areas, only six were located outside the old industrial region. In the next decade, this number increased to eight, and in the following decade to ten. Most of the top metropolitan areas in the 1974–1977 list are still the geographical leaders in American knowledge production, but the dominance of the old industrial cities has been reduced: the New York CMSA fell from 1 to 2, the Chicago CMSA from 3 to 5, the Cleveland CMSA from 9 to 18, the Pittsburgh MSA from 10 to 24, and so on. On the other hand, of the top six Sunbelt cities in the 1974–1977 list, the Austin MSA, the Seattle CMSA, the Phoenix MSA and the Atlanta MSA were new additions to the top 20 in the 1994–1997 timeframe. Furthermore, the San Francisco–San Jose area of the Sunbelt took over the position of leading city, taking that distinction from the New York CMSA.

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[5] Names of metropolitan areas used in this section are abbreviated. For example, New York-Northern New Jersey-Long Island, NY-NJ-CT-PA CMSA was shortened to New York CMSA.

Table 1. Twenty Most Innovative Metropolitan Areas, 1974–1977, 1984–1987, and 1994–1997

Rank	74–77	84–87	94–97
1	New York CMSA	New York CMSA	San Francisco-Oakland-San Jose, CA CMSA
2	Los Angeles CMSA	Los Angeles CMSA	New York CMSA
3	Chicago CMSA	San Francisco-Oakland-San Jose, CA CMSA	Los Angeles CMSA
4	San Francisco-Oakland-San Jose, CA CMSA	Chicago CMSA	Boston CMSA
5	Philadelphia CMSA	Boston CMSA	Chicago CMSA
6	Boston CMSA	Philadelphia CMSA	Detroit CMSA
7	Detroit CMSA	Detroit CMSA	Philadelphia CMSA
8	Washington DC CMSA	Houston CMSA	Minneapolis-St. Paul MSA
9	Cleveland CMSA	Minneapolis-St. Paul MSA	Washington DC CMSA
10	Pittsburgh MSA	Washington CMSA	Dallas CMSA
11	Houston CMSA	Cleveland CMSA	Houston CMSA
12	Minneapolis-St. Paul MSA	Dallas CMSA	Rochester MSA
13	Rochester, NY MSA	Pittsburgh MSA	San Diego MSA
14	Dallas CMSA	Rochester MSA	Austin MSA
15	St. Louis MSA	San Diego MSA	Seattle CMSA
16	Denver CMSA	Seattle CMSA	Phoenix MSA
17	San Diego MSA	Phoenix MSA	Denver CMSA
18	Milwaukee CMSA	Denver CMSA	Cleveland CMSA
19	Cincinnati CMSA	Cincinnati CMSA	Atlanta MSA
20	Albany MSA	HartfordT MSA	Cincinnati CMSA

Using CV, Figure 7 displays how the unevenness of patenting at the metropolitan level has changed over time. The CV had been steadily decreasing until 1989, after which the trend is no longer clear. This may suggest a convergence of knowledge production across cities of different sizes.

However, when broken down, cities of different sizes are not necessarily showing homogeneous trends (see Figure 8). I broke down the cities by both census region and size, see Table 2. With a national patenting growth rate being 120.3%, the growth rates of small and mid-sized cities in the Northeast

and Midwest are not higher than the national average. The cities that create the trend in Figure 7, which more or less looks like convergence, are the large and mid-sized cities in the West and the South. Even in the West and the South, the growth of knowledge production in the largest metropolitan areas is greater than the national average. As a result, interurban convergence is, at most, limited.

Table 2. Patent Growth of Cities by Census Region and by the Number of Employment, 1970s and 1990s.

	U.S	Midwest	Northeast	South	West
Largest Cities	84%	51%	20%	124%	144%
(Over 700,000)	(16)	(5)	(4)	(6)	(2)
Large Cities	95%	28%	42%	111%	197%
(200,000–700,000)	(36)	(10)	(6)	(16)	(6)
Mid-Sized Cities	127%	41%	44%	131%	343%
(50,000–200,000)	(95)	(29)	(13)	(41)	(15)
Small Cities	127%	95%	75%	158%	108%
(below 50,000)	(119)	(30)	(12)	(59)	(20)

-Number of cities in parentheses
-The sum of the number of cities in each region is greater than that of the U.S. as a whole because cities across the border of census regions are counted in both regions.
-Annual employment is an average of yearly employments from 1974 to 1977.
-The examples of each classification are as follows. Largest cities: New York, Los Angeles, and Atlanta; Large cities: Seattle, Milwaukee, and Syracuse; Mid-sized cities: Las Vegas, Austin, and Tucson

5.2. Density of Knowledge Production in Cities

Figure 9 shows the rank of cities in patents/1,000 workers. In the 1974–77 time period, the majority of highly ranked cities are the ones in the Northeast and Midwest regions (Kalamazoo. MI; Rochester, NY; Saginaw, MI, among others). Most of these cities, however, disappear from the top 15 lists of the 1994–97 period. Their places are filled by metropolitan areas in the West and

South (Boise, ID; Austin, TX; Burlington, VT, among others).[6] Confirming my findings in the state-level analysis, cities in the West and South are outperforming the cities in the old core, not only because the number of workers has increased, but also because the former regions now have more innovative firms and workforces.

In the analysis of the number of patents at the metropolitan level, interurban convergence was found to exist, although to a very limited degree. Is this because of the general growth of smaller cities, or is it because knowledge production has moved to smaller cities?

To answer this question, I again calculated the CV shown in Figure 10. The overall trend in the CV of patents per 1,000 workers at the metropolitan level shows relative stability, with a minor fluctuation between the years 1974 and 1993 and an increase after that. The limited convergence in this period, which was found by the analysis of the number of patents in Section 5.1, might

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[6] Among the cities ranked highly, Boise deserves some attention. It was ranked 147 in the 1974–77 period, but jumped to the top in the 1994–97 timeframe. While employment grew mathematically, the patent grant grew exponentially. A close investigation of the row data found that a considerable number of the patents in the Boise MSA is concentrated in three patent categories: 320 patents in class 257, "Active solid-state devices"; 386 patents in Class 365, "Static information storage and retrieval"; and 792 patents in Class 438, "Semiconductor device manufacturing." This concentration is due to prominent technology firms such as the Hewlett-Packard Company, Micron Semiconductor and Micron Display.

simply be the result of the relocation of jobs, rather than of the increasing innovativeness of smaller cities.

The increase in CVs after 1993 indicates that the gap between well-established core cities and lagging cities increased during the period 1993-1997. This tendency is evidence against the convergence argument.

What then is the main driving force behind this change? Based on the analyses at interregional level in Section 4, one can easily guess that it is the emergence of the Sunbelt cities. But which cities in particular? Figure 11 should give us some hints. The cities that exhibited the greatest improvements are located mainly in the West. Among cities in the West, however, the smallest cities do not contribute much. In other words, the improvement is limited to the largest, large, and mid-sized cities. These results, when compared to the growth in sheer number by city size (as reported in Figure 8), show another interesting point. While the sheer number of patents grew faster in the mid-sized cities, patents per worker grew faster in the largest cities. This observed result is another reason to question the convergence argument.

5.3. Interurban Divergence

My interurban analyses revealed that the quantity of knowledge production is growing fastest in mid-sized cities and in small cities. On the other hand, in terms of innovativeness, the gap between mid-sized/smaller cities and larger cities is, for the most part, growing. By combining these two findings, we can tell that the mid-sized/smallest cities' growth in patenting has occurred because

those cities have grown faster than bigger cities in employment, rather than becoming more innovative. Overall, I found little evidence for convergence across cities of different sizes. It seems reasonable to conclude, therefore, that the correlation between a city's size and its knowledge production performance certainly exists, and is probably becoming stronger.

6. Further Discussion

Recent developments in growth theory have found that knowledge production is the single most important factor in long-term economic growth (Aghion and Howitt, 1998; Grossman and Helpman, 1991; Lucas, 1988; Romer, 1986; 1990). It has also been found that the increasing-return effect of knowledge production affects geographically close actors more than it does those that are geographically distant (Acs, 2002; Audretsch and Feldman, 1996; Patel and Pavitt, 1991; Porter, 2000; Smith, 1999; Sonn and Storper, 2003; Storper, 1997). In this situation, the question of convergence and divergence, an issue that has been central to economic geography (Anselin, 1995; Krugman, 1995; Quah, 1997; Williamson, 1965), can be reinterpreted as the convergence and divergence of knowledge production.

This paper explored the NBER Patent Citation Data Files to find a geographic pattern of knowledge production. From the analysis of patent data from the period 1965–1997 and some earlier periods, this paper reveals two main findings: 1) At interregional level the West has emerged as the new center of knowledge production partially replacing the Northeast and the Midwest.

And the South is more or less catching up with the old core; 2) At interurban level, some evidence was found that the gap between the larger cities and smaller cities is growing.

The catch-up of the South at interregional level can be explained by neoclassical theory. On the other hand, the emergence of the West as the new core region is not well explained by major theories in economic geography. The neoclassical location theory explains the beginnings of knowledge production in the West. However, this theory cannot explain why the end result was re-concentration in a new place rather than dispersion. Divergence theories, from Torsten Hägerstrand (1952) to Gunnar Myrdal (1958) to Paul Krugman (1991), explain the persistent excellence of some states in the old core, such as the state of New York, yet none of these theories leave room for the emergence of the West as the new dominant core.

These findings may support Scott and Storper's (1987) and Storper and Walker's (1989) neo-Schumpeterian model of core shift, which argues that new industries are likely to be centered outside the traditional core. According to these authors, radical change in technology is likely to accompany a shift in the industrial cores. The institutional arrangements in an industrial core region are functional relative to the technological paradigm. When a new technological paradigm emerges, if it is not compatible with the old core's existing institutional arrangements—which is usually the case—a "locational window of opportunity" opens for other regions to become a new core. Any region with relatively advanced economic and social conditions can become the new core.

But once one region gets ahead of the others—for any reason—the "locational window of opportunity" closes. The former then becomes dominant while the latter dies out, as divergence theories explain well.

This theory explains, better than any of the well-established theories, the industrial core shift from the Midwest and the Northeast to the West. If this theory holds true, the difference between the West and the rest of the U.S. may increase until a new radical breakthrough in technology occurs.

Another piece of evidence that may support the core-shift model is the temporal gap that exists between the time when the West began to dominate in terms of amount of innovation and the time when it began to dominate in terms of innovativeness of firms. To be a new industrial core, a region should advance its area's qualities in terms of social, political and cultural factors. It may be presumed that the West began to attract companies and workers from less innovative sectors first and that the resulting size effect then caused the West to possess the qualities of an advanced region. In turn, this increase in regional quality allowed the West to attract knowledge production activities. The time gap that exists between the West's emergence as an industrial core and its emergence as a knowledge production core might represent the timeframe the region required to mature into an advanced region.

It is also noteworthy that the interregional divergence began around the 1980s, which might be the geographical manifestation of "Post Fordism" or the "New Economy" becoming the dominant techno-institutional paradigm. Of course, for a long time before the divergence become evident, the new

center must have begun to emerge. The exact time of such emergence cannot be found through this paper's analysis, but Post Fordist literature suggests that this must have occurred in the 1970s. As Saxenian (1994) eloquently described, behind the diverging economic fortunes of the old core and the West, are different interpersonal and inter-organizational relationships. In the West, the workers share information with their colleagues in different companies. It is also peculiar to the West that top management is open to suggestions from bottom-end engineers. Saxenian (1994), along with many others, suggests that this openness is proper to the new economy, where information plays a critical role. Saxenian's findings demonstrate that the institutional arrangements in the old core were not compatible with Post Fordism. In this sense, my finding of the West's emergence as the new core reasonates with Post Fordist literature.

However, in order to conclude that the core shift theory explains the changing inter-regional geography of knowledge production in the U.S., the aggregate patterns found in this paper should be complemented by a sectoral-level analysis. If the West grew as a result of its specialization in newly emerging technology fields, the core shift theory can be validated on more firm grounds.

Another important finding in this paper is that the rise of the Sunbelt is due, in large part, to the rise of the largest and the mid-sized cities in the West, such as San Francisco-Oakland, CA; Boise, ID; and Austin-San Marcos, TX. These cities grew faster than both similar-sized cities in other regions and bigger or smaller cities in the West. In the sense that the growth of mid-sized

cities is limited to the West, the neoclassical explanation of the interurban convergence is only partially correct. The cause of this phenomenon is yet to be discovered.

The majority of economic geographers and regional scientists say that the biggest cities are more innovative than their smaller counterparts. This argument, however, cannot perfectly explain why the mid-sized cities in the West are growing faster than any other group of cities. It is possible that the fast-growing mid-sized cities are actually functional parts of the largest cities, rather than being independent spatial units in and of themselves. Then, their growth would be not because interurban convergence is happening but because the West as a whole is growing as core-shift theory argues. However, to find out if my supposition is true, interaction between mid-sized cities and nearby largest cities should be analyzed. Perhaps an analysis of the citation flow of patents between cities can serve this purpose.

The findings of this paper are that geographical clustering may be a persistent characteristic of knowledge production. While existing clusters may decline, new patterns of clustering will emerge rather than a geographically dispersed landscape of knowledge production. This persistence of the divergence in knowledge production, in turn suggests that in the knowledge-based economy, the location of knowledge production might be a main cause of the geographical unevenness of economic growth and income level. This tendency might be the result of an uneven distribution of factors necessary for knowledge production.

On the other hand, there is some evidence that, initially, new industries attract necessary factors (such as talented workers and capital), rather than of vice versa. If this holds true, although we can predict that new clusters of knowledge production may appear along with new industries, we will seldom know in advance where those clusters will be located.

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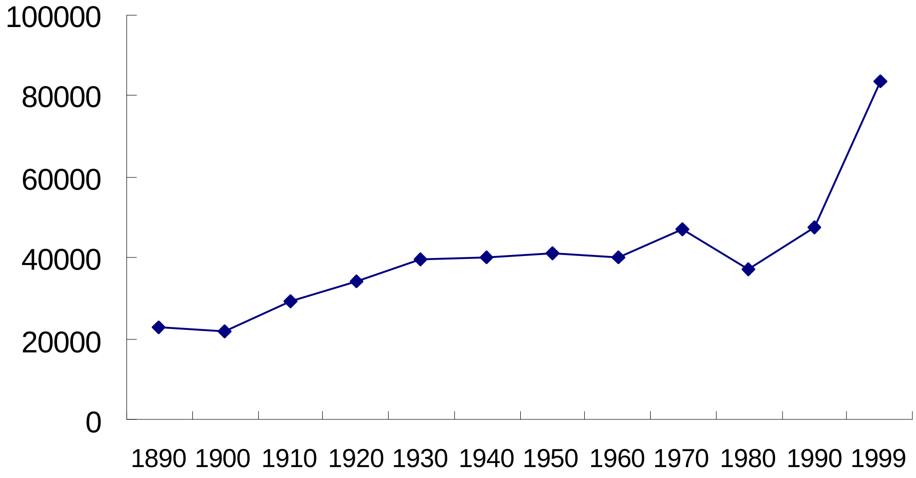


Figure 1. Number of U.S. Patents by U.S. Inventors, by Grant Year

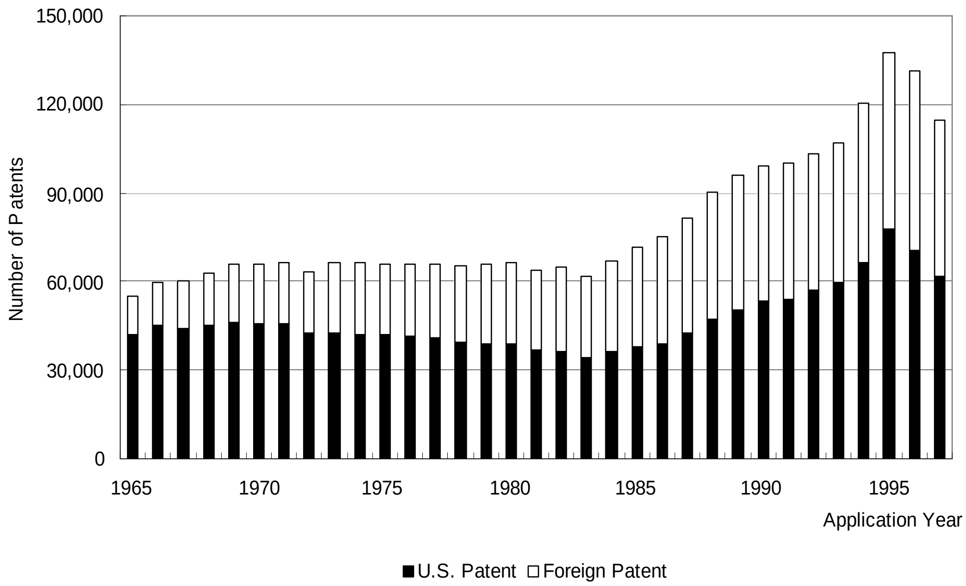


Figure 2. Number of US Patents by US and Foreign Inventors, by Application Year, 1965–1997

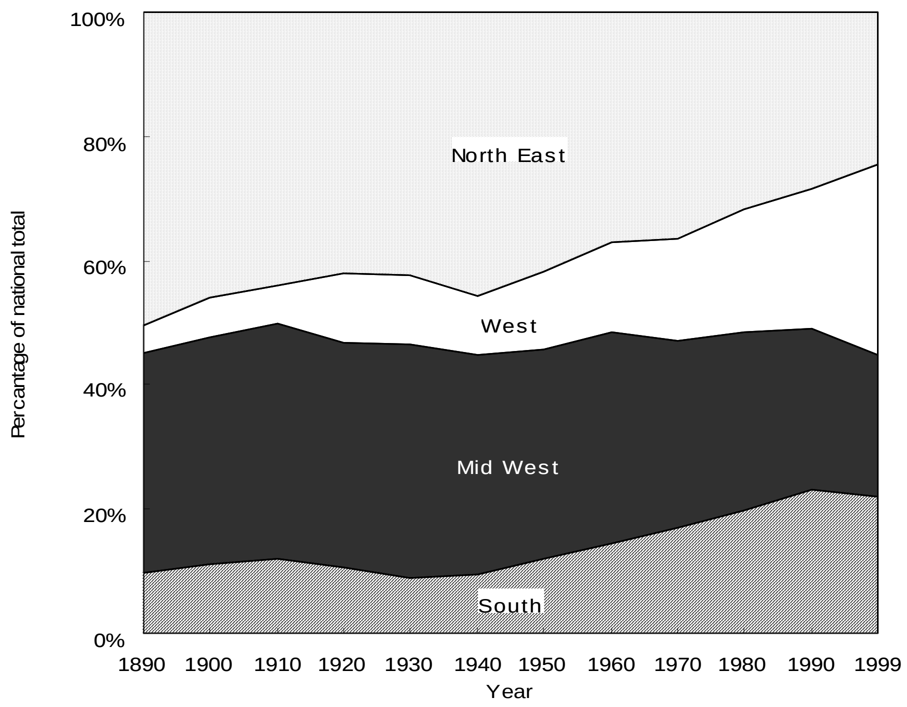


Figure 3. Granted Patents by Census Regions as Share of National Total, 1890–1999

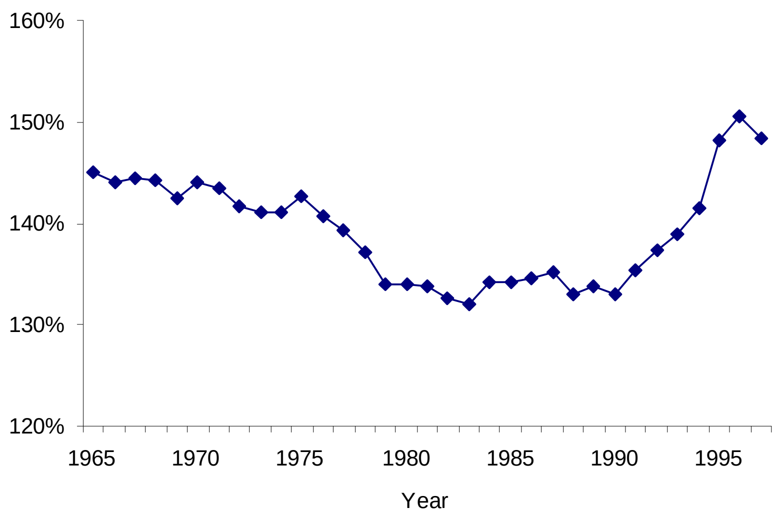
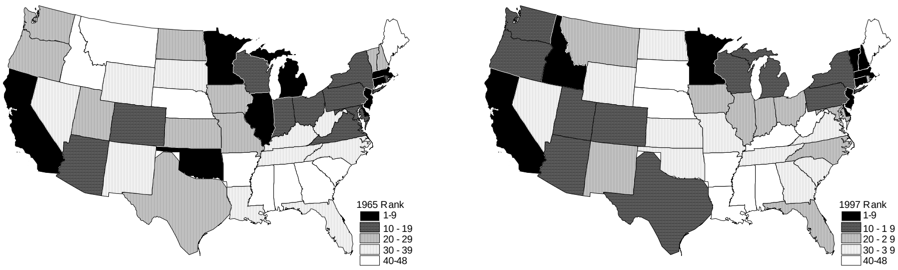


Figure 4. Historical Change of States' CV in Patenting, by Application Year, 1965–1997



a. 1965

b. 1997

Figure 5. Rank of States by Patenting per 1,000 Workers

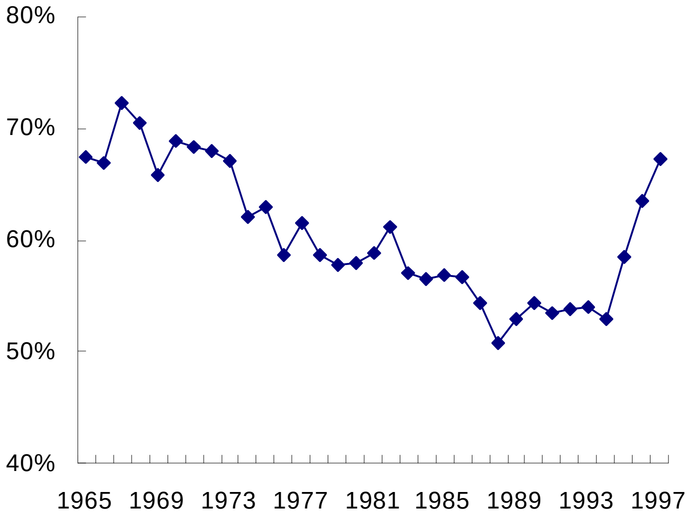


Figure 6. Interstate Unevenness in Patenting per 1000 Workers Measured with Coefficient of Variation, 1965-1997

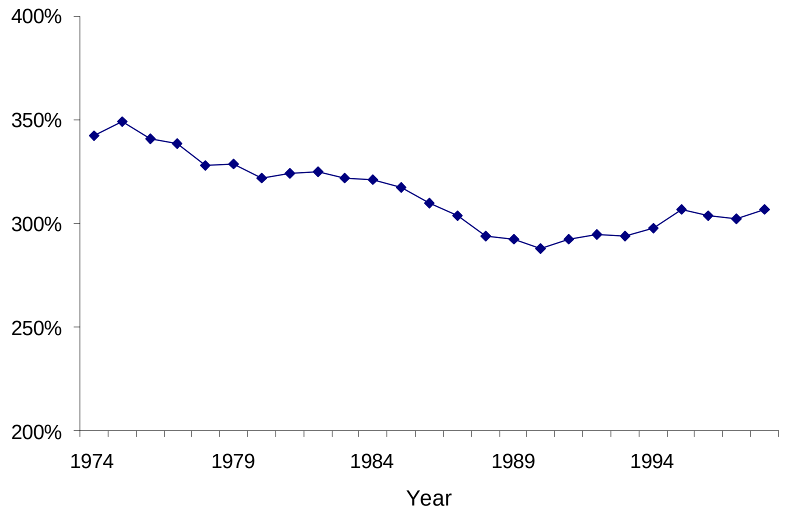


Figure 7. Inter-Metropolitan Unevenness in Patenting Measured with Coefficient of Variation, 1974–1997

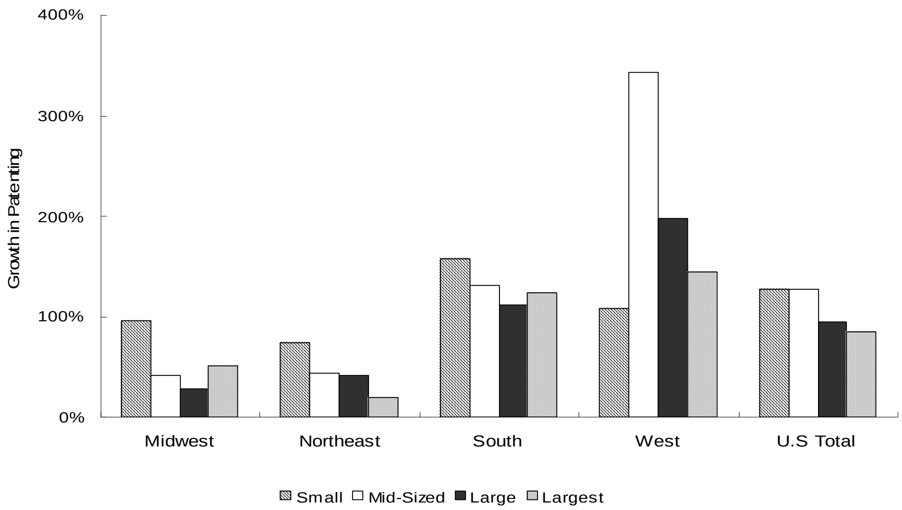


Figure 8. Patent Growth of Cities by Census Region and Size, 1970s and 1990s.

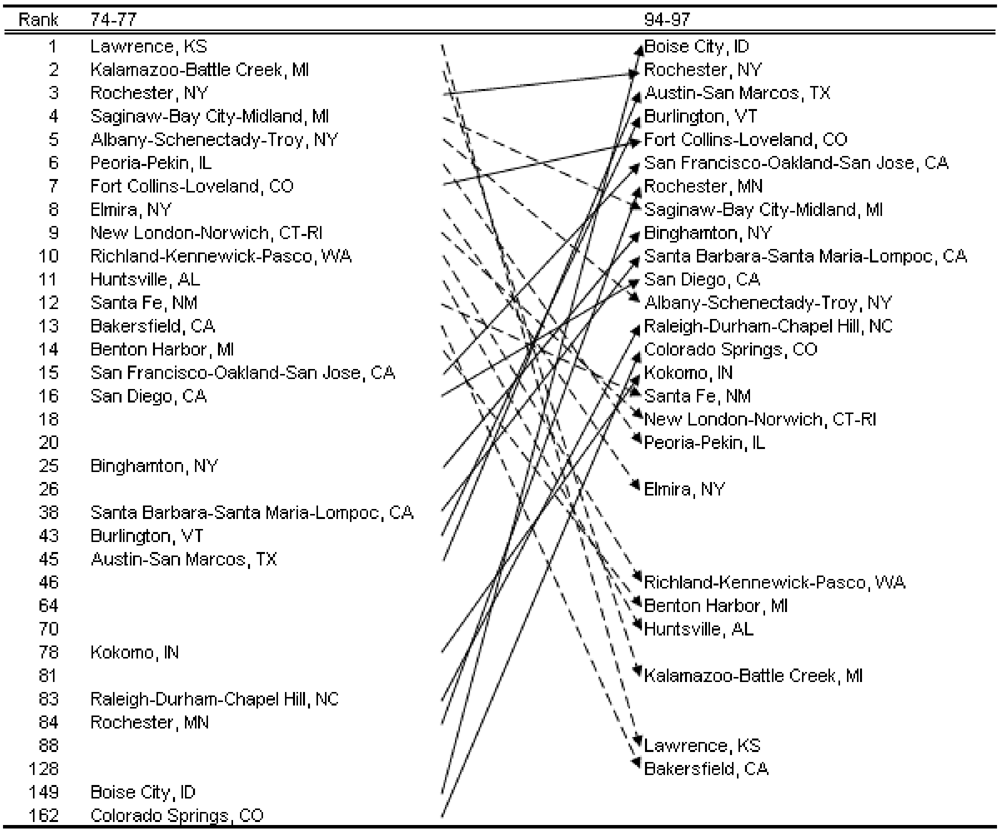


Figure 9. Rank Changes of Cities in Patent per Worker.

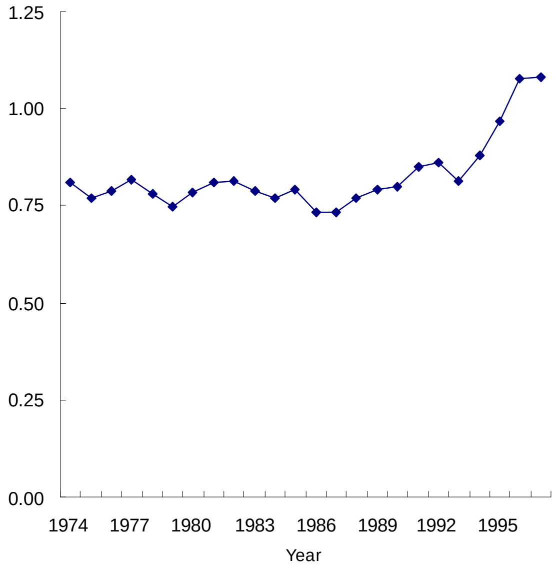


Figure 10. CV of Cities in Patents/1,000 Workers 1974–1997

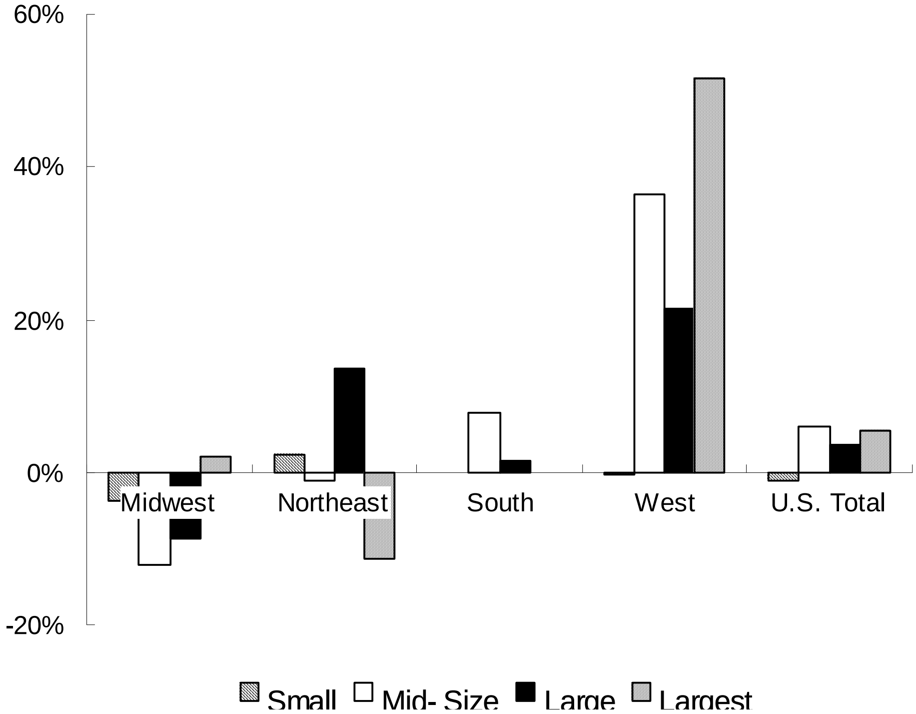


Figure 11. Changes in Patents/1,000 Workers in Cities, by Size and by Region, 1974–77 and 1994–97