Do Only Big Cities Innovate? Technological Maturity and the Location of Innovation

By Michael J. Orlando and Michael Verba

Innovation enhances economic performance. High rates of innovation are associated with high rates of productivity growth, and faster productivity growth leads to higher real wages and improvements in standards of living. Consequently, many local policymakers are eager to encourage higher rates of innovation in their areas.

Theoretical and empirical studies of the geography of innovation find that relatively populous regions are the most conducive to innovative activity. Large and densely populated places offer more developed markets for the specialized inputs used in innovation. Populous places also offer innovators greater opportunities to learn from one another. On the surface, these findings seem to offer little hope to smaller, more sparsely populated regions—places that would like to compete for innovative activity and the benefits of a knowledge economy.

Are large populations a prerequisite for innovation? This article explores this common perception and finds it is not always true. More populous regions dominate in relatively new technological fields, where innovations are more original. But less populous regions can compete in relatively mature technological fields, where innovations are more

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incremental. This finding should be of interest to research and development professionals—and to policymakers who are seeking ways to enhance regional innovative activity.

The first section of this article characterizes innovations and then identifies where they occur. The second section explains why more populous places are generally more innovative than less populated places. The third section explains why less populated places may not be at a disadvantage in promoting innovation in mature technological fields. The fourth section examines evidence from patent activity that is consistent with this view. And the fifth section establishes that the concentration of mature innovative activity in less populated areas is not entirely a result of the types of industries that locate in those places.

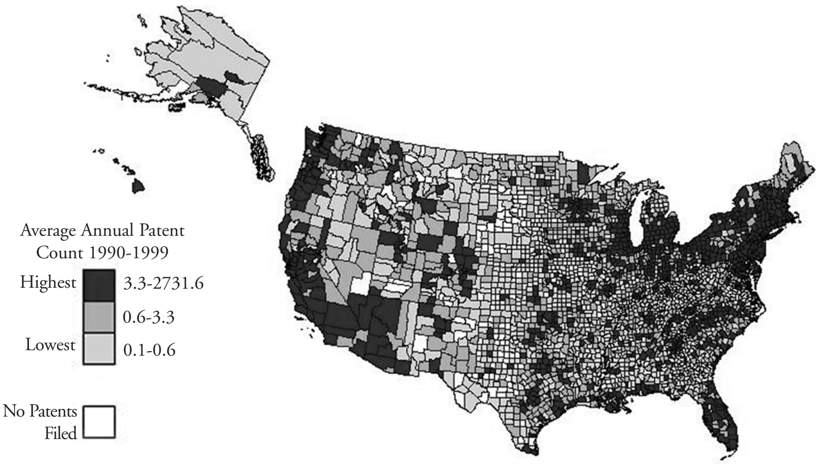
I. WHAT IS INNOVATION AND WHERE DOES IT OCCUR?

Innovations are new ideas that are valued in the marketplace. Some new ideas create value by introducing new products or services. For example, the vacuum light bulb opened the door to an entirely new set of products. Other new ideas improve existing products. A slightly longer golf tee, for example, makes longer drives possible.[1] Still, other new ideas simply make existing products less costly.

Developers of innovative ideas include independent inventors, private industry, and government and university research facilities. These innovators make discoveries in a variety of ways. Inventors create innovations through intentional effort and by chance. Similarly, private industrial research facilities employ scientists and engineers to discover new ideas, while their production line workers may unintentionally discover new ideas during the normal course of operations. Finally, university and government research facilities hire professors and scientists to develop innovative ideas.

Innovation requires three types of inputs: human resources, capital resources, and knowledge. Research labs pay scientists and engineers to think of valuable new ideas. Private and public researchers also invest in specialized laboratory equipment used for discovery. Finally, innovators may purchase technology licenses for the right to use knowledge developed by other researchers.

Figure 1
COUNTY PATENT ACTIVITY



Note: Counties with non-zero patents from 1990 to 1999 are divided into thirds based on the average annual patent count.

Source: National Bureau of Economic Research

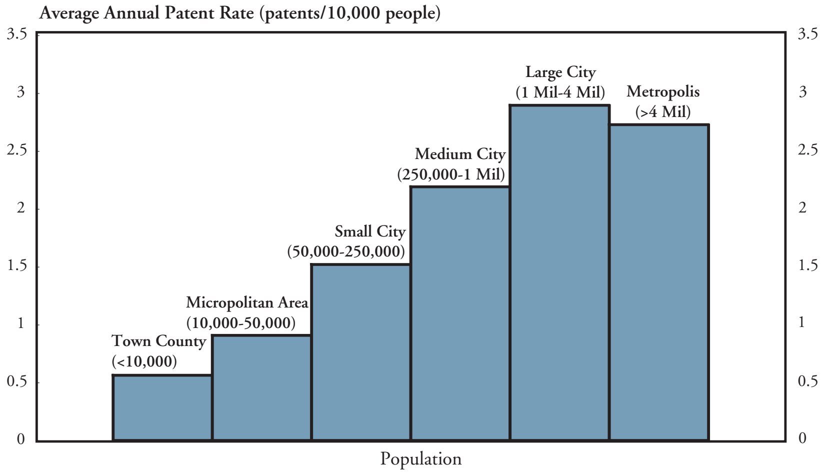
Innovators also acquire knowledge by learning from others. For example, research facilities may reverse engineer the products of other firms to discover related opportunities for innovation. Scientists may attend professional conferences or study the patent applications of other innovating firms. Finally, innovators of all kinds may acquire knowledge through social interaction or by simply hiring away another innovator's employees.

Innovative activity is widely distributed throughout the United States. Figure 1 shows the average annual number of patents granted in each county in the 1990s.[2] As indicated by the dark shading, most of the highest patenting counties are located in the populated coastal regions and cities in the Midwest. However, less populated areas generate patentable innovations as well.

A closer look at the data indicates counties with higher populations exhibit higher rates of innovation in addition to higher levels. The 100 most populous counties accounted for 43 percent of total population in the 1990s, while generating 53 percent of total patents. In contrast, the 100 least populous counties accounted for 0.06 percent of total population but only 0.01 percent of patents.[3] Chart 1 summarizes the average

Chart 1

PATENT PRODUCTIVITY VS. POPULATION



Sources: U.S. Census Bureau and National Bureau of Economic Research.

annual patent rate per 10,000 persons in the 1990s for locations of various sizes. On average each year, cities of 1 to 4 million people produce approximately twice as many patents per person as do smaller cities of 50,000 to 250,000 people.[4] Explaining this disparity is the first step toward understanding what determines the location of innovation.

II. WHY ARE MORE POPULOUS PLACES MORE CONDUCIVE TO INNOVATION?

Rates of innovation are higher in more populous places for two reasons. First, inputs to innovation are cheaper and more readily abundant. Second, more people in one place create more opportunities to learn from others. The higher level of innovation that results reinforces the benefits of concentrating innovative activity in a populous place.

Thick markets in populous places make inputs to innovation cheaper and more readily abundant. Thick markets for any good are generally characterized by a large number of buyers and suppliers. Populous places can support thick markets for even the specialized goods, services, and personnel necessary for innovation. For example, job vacancies for highly specialized researchers are easier to fill in large cities with a greater supply of potential applicants. As a result, populous places allow innovating firms to acquire these specialized inputs more cheaply. The relatively low cost of acquiring these inputs makes researchers in a large city relatively more productive. This benefit is further compounded as suppliers of innovative inputs choose to locate in populous places as well.[5]

Knowledge spillovers make populous areas more innovative because many people in one place create greater opportunities to learn from one another. Knowledge spillovers refer to the ideas acquired by one researcher that are attributable to another researcher's effort. Researchers often learn one another's ideas through professional and social interaction. For example, engineers and scientists learn from their peers when they attend technical meetings. Since many such interactions take place locally, much of the knowledge that spills beyond firm boundaries is confined to a particular region.[6] The benefits of spillovers are amplified as potential innovators locate in populous places to take advantage of this access to knowledge.[7]

The combined benefits of thick markets and knowledge spillovers encourage the concentration of highly skilled labor in populous places.[8] Table 1 summarizes scientific and technical employment for metropolitan areas of various sizes as described in the Bureau of Labor Statistics' *Occupational Employment and Wage Estimates*, 1999. Metros of 1 to 4 million have over twice as many scientists and engineers per capita as metros of less than 1 million. Employees in these high-tech professions often prefer larger cities because they offer more job opportunities. And high-tech employers often prefer to locate in large cities where their employees are more likely to benefit from knowledge spillovers.

The benefits of thick markets and knowledge spillovers also encourage the concentration of high-tech capital goods in more populous places. The 2002 Commodity Flow Survey (CFS), compiled by the U.S. Census Bureau, allows comparison of the volume of high-tech capital goods employed in states.[9] The CFS provides information on shipping patterns of 50,000 establishments chosen on the basis of location and industry. The survey tracks the movement of 40 commodity groups by state of shipment and state of destination. The data presented in Table 2 show that states with more of their population in big cities

Table 1

HIGH-TECH EMPLOYMENT

By population category, 1999 (MSAs only)

Average population level in 1990s (000s)	Scientists and engineers per capita (per 10,000 pop.)
More than 4 million	101
1 million-4 million	94
250,000-1 million	42
50,000-250,000	15

Sources: U.S. Census Bureau, U.S. Department of Labor, Bureau of Labor Statistics

Notes: Population categories and the *Occupational Employment and Wage Estimates* are based on the June 30, 1993, Metropolitan and Micropolitan Statistical Area standards established by the Office of Management and Budget.

Table 2

HIGH-TECH CAPITAL EXPENDITURE

By state share of population in large MSAs

Quintile	Population in MSAs > one million (%)	Expenditure per capita ($)	Expenditure per total state expenditure (%)
1st-top 10 states (Rhode Island, District of Columbia, Maryland, New Jersey, California, New York, Massachusetts, Illinois, Virginia, Nevada)	80	4,390	16.8
2nd	57	4,020	13.6
3rd	38	3,730	10.8
4th	11	2,500	8.3
5th -bottom 11 states (New Mexico, Nebraska, Maine, Hawaii, Idaho, Montana, South Dakota, North Dakota, Alaska, Vermont, Wyoming)	0	2,500	10.5

Source: U.S. Census Bureau, *Commodity Flow Survey*, 2002

Note: States are ordered by percent of population in cities larger than 1 million. States with no cities larger than 1 million are ordered by total state population. Data includes the District of Columbia.

have a greater per-capita expenditure and a greater share of total expenditures on high-tech goods. The 10 states with the largest share of population in cities of more than 1 million spent $4,390 per person on high-tech goods. This figure is 76 percent larger than the average for the 11 least populous states with no cities of 1 million or more. In states with the largest share of population in large cities, high-tech capital goods represented 17 percent of expenditures on all goods, compared to 11 percent in states without very large cities.

Thick markets and knowledge spillovers suggest that large cities are more productive places for innovative activity. Consistent with this view, high-tech workers and high-tech capital are employed disproportionately in large cities. The resulting concentration of innovations compounds the benefits of locating such activity in a populous place. The advantage of size for innovation is a significant challenge for smaller, less populous places that aspire to share in the benefits of the knowledge economy.

III. HOW COULD TECHNOLOGICAL MATURITY AFFECT THE LOCATION OF INNOVATION?

While the overall rate of innovation is higher in populous places, some innovative activity is disproportionately located in remote areas. For example, as a share of total patents in sparsely populated counties, patenting in the classifications of earth working equipment, track sanders, and mineral oils is over 10 times larger than the nationwide share of patents in these classes. Understanding why this innovation disproportionately locates in less populated areas requires identifying the distinguishing features of such innovative activity.

Technological maturity is one feature that explains why some types of innovative activity may not be at a disadvantage in a less populated place. Mature technological fields are those in which the path of innovation is relatively predictable. Greater predictability allows innovators to use information and transportation technologies to mitigate the disadvantages of remoteness.

The importance of technological maturity for the location of innovation is best understood in the context of the technological life cycle. The technological life cycle describes the path of development of a typical technology. Early in its history, when a technology is first emerging, innovations will be original and low in number. Over time, more is learned about the nature of the problems addressed in the technological field. Innovative activity will increase as later innovations build on earlier discoveries.

At some stage, the benefit of building on earlier discoveries will be overcome by the declining rate of opportunities in the field. The rate of innovations will peak as the discipline matures. Eventually, opportunities for the discovery of new innovations will be exhausted, and the annual number of innovations will begin to decline. Finally, a low residual level of innovation may persist as relatively incremental improvements are made to a well-established state-of-the-art.

Knowing the stage of maturity in a technology's life cycle sharpens our understanding of how population benefits innovation in a field. The advantage of population is particularly acute for innovations that occur in the early phases of the technological life cycle. The ultimate sequence of innovations is relatively uncertain while each innovation is relatively original. At this stage, the basic knowledge, materials, and scientific hardware necessary to achieve the next innovation only become known as the path of discovery unfolds.

Given the relatively uncertain path of innovation in emerging fields, the thick markets and knowledge spillover advantages of populous places are particularly important for learning. Only thick markets enable innovators to acquire specialized inputs quickly and cheaply. Since innovators do not know exactly what inputs they will need next, they place a relatively high value on these thick-market benefits. They also place a high value on the knowledge spillover benefits of population, such as the greater number of chance encounters with other scientists and engineers in a populated place. For example, researchers in the relatively new field of artificial intelligence data processing cannot be sure what software and human capital will be required to improve on this technology over the short term. As a consequence, they rely more heavily on unplanned spillovers from other researchers.

In mature technological fields, successive innovations are relatively incremental. The benefits of population due to thick markets and knowledge spillovers are not as significant because the path of innovation is more predictable. Predictability in the sequence of innovations translates into predictability of the basic material, equipment, and knowledge inputs required to produce the next innovation.

The learning required to innovate in mature fields is more amenable to planning. As a result, transportation and communication technologies are more effective substitutes for proximity. Greater foresight allows researchers to buy inputs inexpensively that may not be readily available in local markets. For example, researchers in the relatively mature field of earth working equipment can anticipate the specialized instruments and software needed to develop the next innovation. A greater ability to identify opportunities for knowledge spillovers also allows innovators to plan for productive meetings in advance, rather than leaving learning to chance. Even in remote locations, researchers can acquire knowledge from others if they know exactly whom to contact.[10] Thus, by locating in a less populous area, researchers in mature fields can continue to innovate while taking advantage of the lower cost of doing business in such areas.

IV. EVIDENCE ON TECHNOLOGICAL MATURITY AND THE LOCATION OF INNOVATION

Researchers in mature technological fields can anticipate input requirements for discovery. As a result, they will not be disadvantaged by locating in sparsely populated places to avoid the high cost of operating in the city. New data on technological maturity of innovation by geographic area support this hypothesis. Specifically, the data show that mature innovative activity is disproportionately located in less populated areas.

The analysis examines patent activity from 1990 to 1999 in 2,295 geographic areas. These areas consist of metropolitan areas, micropolitan areas, and town counties.[11] Table 3 reports descriptive statistics for a representative selection of these areas. Populations range from 101 persons in Loving County, Texas, to over 17 million in the New York metro area. The area with the average population (Kahului-Wailuku, Hawaii) has more than five times as many people as the area with the median population (Randolph, Alabama), indicating that the distribution is skewed toward smaller areas. In other words, there are a small

Table 3

PATENTS AND POPULATION FOR SELECTED AREAS

1990-99 average

Area name	Population level (thousands)	Average annual number of patents	Relationship to entire sample
New York-Northern New Jersey-Long Island, NY-NJ-PA MSA	17,500	4,240	max. no. patents max. population
Los Angeles-Long Beach-Santa Ana, CA MSA	11,700	2,920	2nd by patents 2nd by population
San Jose-Sunnyvale-Santa Clara, CA MSA	1,620	2,740	3rd by patents 28th by population
Chicago-Naperville-Joliet, IL-IN-WI MSA	8,640	2,460	4th by patents 3rd by population
Boston-Cambridge-Quincy, MA-NH MSA	4,230	2,080	5th by patents 9th by population
San Francisco-Oakland-Fremont, CA MSA	3,890	1,870	6th by patents 11th by population
Austin-Round Rock, TX MSA	1,020	775	18th by patents 50th by population
Denver-Aurora, CO MSA	1,890	429	28th by patents 26th by population
Kansas City, MO-KS MSA 1,	1,730	186	55th by patents 28th by population
Sayre, PA MicroSA	62	25	average no. patents
Kahului-Wailuku, HI MicroSA	115	8	average population
Rockingham, NC MicroSA	46	.9	median no. patents
Randolph County, AL	21	.2	median population
Adair County, OK	20	0	min. no. patents
Loving County, TX	.101	0	min. no. patents min. population

Sources: U.S. Census Bureau, National Bureau of Economic Research number of highly populated areas and a large number of less populated areas. Patenting activity is skewed even more than population. The number of patents granted inside the geographic unit with the average number of patents (Sayre, Pennsylvania, a micro area) is 28 times greater than the number of patents issued in the area with the median number of patents (Rockingham, North Carolina, a micro area).

Maturity measures based on patent class characteristics

One way to evaluate the effect of technological maturity on the geographic distribution of innovations is to see if innovations in later stages of the technological life cycle tend to locate in less populated areas. The U.S. Patent and Trademark Office (USPTO) groups patents into roughly 400 classes according to characteristics of the associated innovation.[12] By examining patent activity during the entire period 1963 to 1999, it is possible to determine the stage in the technological life cycle of each patent class during the 1990s, the last decade for which data are available. Patents issued in patent classes that were in late stages of the life cycle in the 1990s are considered to be relatively mature.

Patent classes can be divided into six categories reflecting the different stages of the technological life cycle. Patent classes in which patent activity was rising in the late 1990s are defined as *expanding*. Classes in which patent activity was stable at or near its historical peak are defined as *high plateau*. These two categories are assumed to be in the early stages of the life cycle. Thus, patents in these classifications awarded in the 1990s are considered relatively original in the historical context.

Classes in which patent activity was falling in recent years are defined as *declining*. Classes in which patent activity appears to have declined to a stable rate below historical peaks are defined as *low plateau*. These two categories are assumed to be in the late stages of the classification life cycle—thus, these technologies are considered relatively mature and patents issued in these categories in the 1990s are relatively incremental in the historical context.

Table 4

LIFE CYCLE OF PATENT ACTIVITY

(By population of area)

Average area population level in 1990s	Expanding (%)	High plateau (%)	Declining (%)	Low plateau (%)	Sparse/ extinct (%)	Not determined (%)	Total (%)
More than 4 million	61	7	5	8	0	20	100
1 million– 4 million	65	7	3	6	0	18	100
250,000– 1 million	57	7	5	9	0	22	100
50,000-250,000	54	8	5	9	0	24	100
10,000-50,000	45	8	4	12	0	30	100
Less than 10,000	42	8	4	14	0	33	100
US Total	*60*	*7*	*4*	*8*	*0*	*21*	*100*

Sources: U.S. Census Bureau, National Bureau of Economic Research

Notes: This table is based on the class life-cycle category in 1999 of patents issued during the 1990-1999 period. See the appendix for the definition of class life-cycle categories. Population categories are based on the December 2003 Metropolitan and Micropolitan Statistical Area standards established by the Office of Management and Budget.

The final two types of classes are not easily defined. *Sparse* or *extinct* classes are those with very little patent activity. Patent activity in *not determined* classes did not exhibit a discernible pattern. A detailed description of the criteria used to assign patents classes to the various life-cycle categories is included in the appendix.

Table 4 presents the percentage of patents in each patent life-cycle category for six geographic areas of various sizes. The data show that more populous areas have a higher proportion of patents in patent classes with expanding levels of innovative activity, while less populated areas have a relatively higher proportion of patents in patent classes at later stages of development. For example, in metro areas of more than 4 million people, 61 percent of patents are in expanding patent classes. But in rural counties—those with less than 10,000 people—only 42 percent of patents are in expanding classes. Similarly, the smaller the population of an area is, the higher the proportion of patents is in low-

Table 5

PEAK PATENT YEAR AND CLASS ESTABLISHMENT YEAR

(By population of area)

Average area population level in the 1990s	**Average peak year**	**Average class establishment year**
More than 4 million	1993	1962
1 million–4 million	1994	1965
250,000–1 million	1992	1961
50,000-250,000	1992	1958
10,000-50,000	1990	1952
Less than 10,000	1989	1948
US Total	*1993*	*1962*

Sources: U.S. Census Bureau, National Bureau of Economic Research

Notes: Population categories are based on the December 2003 Metropolitan and Micropolitan Statistical Area standards established by the Office of Management and Budget. Average "peak" and "class establishment" years are based on patents issued during the 1990-1999 period.

plateau patent classes. While low-plateau patent classes account for only 8 percent of all patents in very large cities, these classes account for 14 percent of patents in less populated areas.[13]

Two other measures of technological maturity based on patent classes help check the robustness of these results. The first of these alternative measures is the peak year of patent activity in the class. Classes in which annual patent activity is at a peak or peaked relatively recently are assumed to be new classes. Classes in which annual patent activity peaked sometime in the distant past are assumed to be relatively mature. The second alternative measure of technological maturity is the year in which the patent classification was first established. Classes established relatively recently are assumed to be new and characterized by a disproportionate share of original patent activity in the 1990s. Classes established in the distant past are assumed to be relatively mature.

Table 5 shows that patents granted to primary investigators in more populous areas tend to come from newer patent classifications. Both peak patent year and patent class establishment year are relatively more recent for patents in large urban areas. In contrast, patents in sparsely populated counties have relatively older peak patent and patent class

Table 6

AVERAGE ORIGINALITY COEFFICIENT

(By population of area)

Average area population level in 1990s	**Average patent originality coefficient**
More than 4 million	.34
1 million – 4 million	.34
250,000 – 1 million	.32
50,000-250,000	.30
10,000-50,000	.27
Less than 10,000	.26
US Total	*.33*

Sources: U.S. Census Bureau, National Bureau of Economic Research

Note: Population categories are based on the December 2003 Metropolitan and Micropolitan Statistical Area standards established by the Office of Management and Budget. Average patent originality coefficients are based on patents issued during the 1990-1995 period. Meaningful originality coefficients could not be estimated for patents issued in later years due to truncation of citation data.

establishment years. On average, for patents granted in areas with 4 million or more residents the establishment of the patent class is 14 years later than for patents granted in rural areas. The average peak patent year follows a similar pattern, occurring later in large urban areas than in rural areas. However, the pattern is less pronounced than for the establishment year, possibly because the secular increase in patenting activity since the early 1980s has reduced the difference in peak patent years between the various geographic areas.

Originality: A patent-specific measure

A final, patent-specific measure provides evidence that relatively incremental innovative activity locates in less populated areas. Each patent generally cites a number of other patents that intellectually precede it. In addition, each patent is generally cited by other patents for which it is a predecessor. The number of citations received by a patent is computed as a fraction of those citations plus the total number of citations made by the patent. For example, a patent that receives as many citations as it makes would have an index value of 0.50.

Table 6 presents the average patent originality coefficient by population level. The average value of the originality index in the least populous counties is 0.26. That is, for patents awarded in these counties, the number of citations received is approximately one-fourth of the total number of citations received and made. Thus, consistent with the findings in Tables 4 and 5, patents in less populated counties are relatively incremental. In contrast, the patents awarded in the most populous metro areas are relatively original. The average patent originality index in metros larger than 1 million is approximately one-third larger than that in the small counties, indicating that patents in populous places tend to be cited much more by other inventions.

V. CAN INDUSTRIAL LOCATION EXPLAIN THE RELATIONSHIP BETWEEN TECHNOLOGICAL MATURITY AND THE LOCATION OF INNOVATION?

Both patent-class and patent-specific measures of technological maturity support the view that innovation in mature classes is disproportionately located in less populated areas. However, many mature technological classes happen to be related to the natural resource and agricultural industries. These industries are disproportionately located in less populated areas. Examples of such mature technological classes include unearthing plants, farriery, and earth working equipment. If the location of innovation is determined by the location of related industries rather than technological maturity of the class, then the concentration of mature innovative activity in less populated areas may be coincidental. Innovations in mature technological classes would be disproportionately located in less populated places because natural resource and agricultural operations are disproportionately located in these areas.

One piece of evidence against this view, presented in Table 7, is the relationship between the average originality of patents and population in classes most closely related to resource and agricultural industries. Unsurprisingly, the originality coefficients for resource and agricultural related classes are generally smaller than the originality coefficients for all technological classes presented in Table 6. Most important, however, is that the originality coefficient increases with population in these

INNOVATIVE ACTIVITY IN THE TENTH FEDERAL RESERVE DISTRICT

(For patents issued during the period 1990-99)

State	Population in MSAs >one million (%)	Average annual number of patents per 10,000 capita	Percent of patents in 'expanding' category	Percent of patents in 'low plateau' category	Average patent peak year	Average patent class establishment year	Average patent originality coefficient
U.S. Total	**53**	**2.23**	**60**	**8**	**1993**	**1962**	**.33**
*Highest U.S. State**	*100*	*6.12*	*77*	*21*	*1995*	*1972*	*.46*
*Lowest U.S. State**	*0*	*.48*	*33*	*4*	*1987*	*1943*	*.20*
District States	**35**	**1.64**	**55**	**10**	**1992**	**1959**	**.31**
Missouri	57	1.32	54	12	1991	1957	.30
Colorado	50	2.99	68	6	1994	1963	.35
Oklahoma	31	1.57	38	12	1989	1957	.25
Kansas	26	1.09	48	16	1990	1954	.27
New Mexico	0	1.48	53	6	1992	1959	.32
Nebraska	0	.97	50	13	1991	1952	.29
Wyoming	0	.85	42	10	1989	1943	.21

* The state featured in these rows is not the same for all columns.

Notes: District states sorted by percent of population in Metropolitan Statistical Areas with population above 1 million. Average patent originality coefficient was calculated based on patents issued during the period 1990-1995 due to truncation of patent citation data for the most recent patents.

The overall pattern of innovative activity in the Tenth Federal Reserve District is consistent with the findings of this article. The population of the Tenth Federal Reserve District is relatively less concentrated in large cities than the U.S. population as a whole. Roughly one-third of the population in the seven District states is located in metropolitan areas larger than 1 million residents. This is almost 20 percentage points below the nationwide proportion of the population living in such areas. As expected given the lower number of people in large cities, the average number of patents produced annually for every 10,000 District residents is 26 percent lower than the national patent per capita rate. In addition, the patents produced in the seven District states tend to be slightly older and less original than the average U.S. patent. This is in accordance with the main empirical finding of this paper that high population results in higher levels of patent productivity and relative specialization in less mature and more original innovations.

Although the Tenth District exhibits lower overall rates of patenting and greater specialization in mature innovation, the innovative output of the region varies considerably across states. Colorado is the most innovative District state, exceeding the national average in all categories of innovation. It produces 2.99 patents per 10,000 persons per year, which is higher than both the District and the national average. Colorado patents come from relatively young classifications and tend to receive slightly more citations than the average patent issued in the United States. Wyoming is at the opposite end of the spectrum. The state produces 62 percent fewer patents per person per year than the United States, and patents in Wyoming tend to be older, with lower originality coefficients.

The other five District states are broadly similar in patent productivity but can be divided into two groups based on the originality of their patents. Missouri, New Mexico, and Nebraska are are more heavily concentrated in younger, original technologies. Although they are typically below the U.S. average on most of these measures, the difference is often small. Innovative activity in Oklahoma and Kansas is more heavily concentrated in long-established, mature technologies. The percent of patents in 'expanding' classifications is low in these states and the percent of patents in 'low plateau' classifications is high. The prevalence of more mature innovations in Oklahoma and Kansas may be in part due to the importance of mature industries to their economies. Kansas depends heavily on aerospace and farming, while natural resource extraction is one of Oklahoma's bedrock industries. These industries tend to support innovations in long-established technologies.

Table 7

AVERAGE ORIGINALITY COEFFICIENT OF PATENTS IN NATURAL RESOURCE AND AGRICULTURAL CLASSES

(By population of area)

Average area population level in the 1990s	Average patent originality coefficient
More than 4 million	.27
1 million–4 million	.25
250,000–1 million	.26
50,000-250,000	.24
10,000-50,000	.24
Less than 10,000	.22
U.S. Total	*.26*

Source: U.S. Census Bureau, National Bureau of Economic Research

Note: Population categories are based on the December 2003 Metropolitan and Micropolitan Statistical Area standards established by the Office of Management and Budget. Average patent originality coefficients are based on patents issued during the 1990-1995 period. Meaningful originality coefficients could not be estimated for patents issued in later years due to truncation of citation data.

classes. In other words, agricultural and natural resource patents awarded in populous places are more widely cited than those awarded in less populous places.

A closer look at the evolution of patent location over time also suggests that patent activity tends to move into less populated locations as a patent class matures.[14] For classes established between 1963 and 1970, Table 8 shows how patent activity depends on the number of years since class establishment. Within the first 10 years of class establishment, 40 percent of patents were awarded in metros of over 4 million while only 31 percent were located in metros under 1 million. In the 1990s, 20 to 30 years after these classes were established, the share of patents awarded in the largest metros fell to 33 percent, while the share awarded in smaller areas rose to 35 percent. Thus, over time, fewer patents were awarded in the largest metros and more patents were awarded in the smaller areas.

A detailed examination of the citation history of a particular patent underscores the importance of population for innovation in the early stages of a new technology. On August 16, 1983, Richard Axel, Saul Silverstein, and Michael Wigler filed one of the first patents involving technology for manipulating DNA. This patent, called "[p]rocesses for

Table 8

DISTRIBUTION OF PATENTS ACROSS POPULATION CATEGORIES

(By number of years between class establishment year and patent issue—for classes established between 1963 and 1970 only)

Average area population level in 1990s	**0 to 10 years (%)**	**10 to 20 years (%)**	**20 to 30 years (%)**
More than 4 million	40	36	33
1 million–4 million	29	29	33
Less than one million	31	36	35
250,000–1 million	18	20	20
50,000-250,000	6	8	7
10,000-50,000	5	6	6
Less than 10,000	2	2	2
Total	*100*	*100*	*100*

Source: U.S. Census Bureau, National Bureau of Economic Research

Note: Population categories are based on the December 2003 Metropolitan and Micropolitan Statistical Area standards established by the Office of Management and Budget.

inserting DNA into eucaryotic cells and for producing proteinaceous materials," would help lay the groundwork for gene splicing technology.[15] At that time, the USPTO, which maintains records on all U.S. inventions since 1790, had only 61 inventions in the class and subclass to which this patent was assigned.[16] Within five years, the number of inventions in this technological category would more than triple to 192 patents. And over the following two decades over 12,610 new patents relating to the manipulation of nucleic acid would be filed with the USPTO.[17]

The invention cited in Axel and others was made by primary investigators affiliated with Columbia University in New York City—the most densely populated metro area in the United States. In the first eight years after the patent was filed, the vast majority of patents citing it were also located in large metro areas. Eighty-nine percent of citations came from inventors located in metros with 1 million or more residents; only 11 percent of citing patents were granted to inventors located in metros with a population of less than 1 million. In the subsequent eight years, the percentage of citations made by primary investigators in cities with a population above 1 million decreased to 64 percent, while the percentage of citations from inventors located in cities with less than 1 million residents increased to 36 percent. The majority of innovations relating to the manipulation of DNA continue to be made by inventors in large metro areas, but as this technology matures, innovators in less populous areas are making an increasing contribution to the development of this field.

VI. CONCLUSIONS

Populated areas have two important advantages for attracting innovative activity. They have thick markets that reduce the cost of acquiring the specialized skills and equipment used in innovation, and they provide greater knowledge spillovers, which make skilled labor more productive. These advantages result in higher overall rates of patent activity in populated areas.

This article argues that the advantages of population are greater for innovations in newly emerging technologies than for innovations in mature technologies. The path of discovery in new technologies is difficult to predict. Consequently, innovators that hope to compete in such technologies need the knowledge spillovers and thick markets advantages that are greater in a populous place. Conversely, incremental innovations associated with mature technologies are easier to anticipate and therefore more amenable to planning. Innovators that can plan in advance can locate in a less populated place and avoid the high cost of doing business in a big city.

The empirical findings of this article support the view that the location of innovation depends on technological maturity. The analysis shows that the share of total innovations in newly emerging technological classes is higher in heavily populated areas than in less populated areas. The patent citation data also suggest that the patent activity that occurs in populated areas is relatively original. In contrast, a greater share of total innovations in less populated areas is incremental and occurs in mature technological classes.

The technological maturity of innovative activity is one factor that research and development professionals can use to guide the location of innovative inputs. Resources devoted to innovation in emerging fields may be most productive in areas where researchers can benefit from thick markets and knowledge spillovers. Resources devoted to innovation in mature fields may be effectively located where planning can substitute for the advantages of population.

The findings of this article can also guide development professionals seeking to enhance the innovative capacity of their regions. Policies that mitigate distance from thick markets and from sources of knowledge spillovers can make less populous places attractive to innovators in mature technological fields. For example, high-quality communication and transportation infrastructure may allow innovators to collaborate with distant colleagues and acquire specialized equipment that may not be available locally. These technologies may represent critical needs for innovators in mature technological fields who would like to take advantage of the low congestion and high natural amenity benefits of many smaller cities.

APPENDIX

The life-cycle category of a patent class in the 1990s was determined on the basis of yearly patent counts for the period 1963-99. The table below explains in greater detail the assignment of patent classes to six general life-cycle categories.

Criteria for assigning life-cycle categories to patent classifications

Life-cycle category	Criteria
Expanding	An expanding life-cycle category was assigned to a patent class when the patent classification met one of two sets of conditions: Set 1 for the ten-year period 1990-99: a) The class' patent frequency exhibited an increasing trend and b) the patent class experienced at least three consecutive years of rising patent frequency. Set 2: a) The class patent frequency exhibited an increasing trend and b) the number of patents issued within the class peaked in 1996-99.
Declining	A declining life-cycle category was assigned to a patent class when the patent class met one of two sets of conditions: Set 1 for the ten-year period 1990-99: a) The class' patent frequency exhibited a declining trend and b) the patent class experienced at least three consecutive years of falling patent frequency.

Declining Cont.	Set 2: a) The class' patent frequency exhibited a declining trend and b) the patent class maximum patent frequency was NOT observed 1996-99.
High Plateau	A high plateau life-cycle category was assigned to a patent class when the patent classification met ALL of the following three conditions: a) The patent classification did not fully satisfy the criteria for emerging and declining life-cycle categories. b) The patent class exhibited general patent count stability over the period 1990-99. c) The classification's patent frequency for at least one of the past 10 years (1990-99) included the maximum patent frequency.
Low Plateau	A low plateau life-cycle category was assigned to a patent class when the patent class met ALL of the following three conditions: a) The patent class did not fully satisfy the crteria for emerging and declining life-cycle-categories. b) The patent class exhibited general patent count stability over the period 1990-99. c) The classification's patent count did NOT include the maximum patent frequency during the past 10 years (1990-99).
Sparse/Extinct	A sparse/extinct life-cycle category was assigned to a patent classification when it met at least one of the following two conditions: a) The class' patenting frequency exhibited significant gaps between years.

Sparse/Extinct (cont)	b) Patenting activity was not observed within the class during the period 1990-1999.
Undetermined	The 'undetermined' category was assigned to a patent classification when the classification did not clearly satisfy the criteria of any of the five patent life-cycle categories defined above.

ENDNOTES

[1]"Building a Better Golf Tee—High-Tech Offerings Claim to Boost Aim and Distance; At Least 764 Patents on File," by Timothy Aeppel, *The Wall Street Journal*, 12 October 2004.

[2]Patents are assigned to the county location of the principal investigator.

[3]Two hundred and sixty out of 3,141 U.S. counties did not generate any patents during the 1990s.

[4]A simple regression by county of patents per capita against population and population squared confirms the significance of the relationship illustrated in Chart 1. The population coefficient is positive and statistically significant. In addition, the population squared coefficient is negative and statistically significant, indicating the total patent rate rises with population to a point and then declines, perhaps as congestion effects set in.

[5]Glaeser.

[6]See Orlando or Jaffe and others.

[7]Audretsch and Feldman document a disproportionate concentration of innovative activity in knowledge intensive industries.

[8]Glaeser also argues thick market and learning advantages make inputs to innovative activity more productive in populous places.

[9]Commodity Flow Survey (2002), *www.census.gov/econ/www/cfsnew.html*. This article considers two commodity groups tracked by the survey—"electronic and other electrical equipment and components and office equipment" and "precision instruments and apparatus"—as high-technology inputs to innovation. This data is unavailable at the MSA level of disaggregation.

[10] Although less populated places have a comparative advantage in mature innovative activity, more populated places may have a higher absolute number of innovations in mature classes simply because they have many more people.

[11]By definition, metropolitan statistical areas contain at least one urban center with a population of at least 50,000. Micropolitan statistical areas consist of one or more counties that include an urban area with population of at least 10,000 but less than 50,000. Counties with no urban area larger than 10,000 are called town counties. The findings presented below are unchanged when the analysis is based on the 3,141 underlying county units. These findings are also unchanged when the analysis is based on population density rather than population level.

[12]The USPTO issues three different types of patents: utility patents, design patents and plant patents. Utility patents cover the structure, operation and application of new products or processes; design patents cover only the ornamental appearance of products; and plant patents cover certain types of living organisms. Most patents issued by the USPTO are utility patents. Only utility patent classes are included in this analysis.

[13]A larger proportion of patents in small areas are also in classifications whose stage in the technological life cycle could not be determined. This is a diverse group of patent classifications that do not fully meet the identification criteria of another technological life-cycle category. These classes exhibit a significant amount of patent activity so they cannot be classified as sparse/extinct. In addition, "not determined" classes could not be assigned to any other life cycle

category either because multiple expansion and contraction phases were observed during the observational period 1963 to 1999 or because the last decade of the observational period did not exhibit a clearly expanding, stable or declining trend in patenting activity. Those classes that exhibited a rise and fall in patenting activity prior to the last decade of the observational period could be considered to be relatively more mature as well.

[14]Due to data limitations, classifications with a "class established" year between 1963 and 1970 are the only classes for which complete patent histories are available.

[15]USPTO Patent Number 4,399,216.

[16]USPTO Class/subclass: 435/6–"Chemistry involving biology and microbiology: involving nucleic acid."

[17]This is the total number of patents issued from August 16, 1983, to February 22, 2005.

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