# Knowledge Spillovers:
## Cities' Role in the New Economy

BY GERALD A. CARLINO

In the smokestack era, cities were centers of manufacturing. What role do cities play in the "new economy"? In this article, Jerry Carlino discusses the link between economic growth and the concentration of people and firms in cities. In particular, he focuses on "knowledge spillovers." These spillovers facilitate the exchange of ideas, promoting creativity and innovation.

Most countries make sustained economic growth a principal policy objective. Although many factors contribute to economic growth, recent research has found that innovation and invention play an important role. Innovation depends on the exchange of ideas among individuals, which economists call knowledge spillovers. For example, a given company's innovation may stimulate a flood of related inventions and technical improvements by other companies.

Recently, some economists have suggested an important link between national economic growth and the concentration of people and firms in cities. The high concentration of people and firms in cities creates an environment in which ideas move quickly from person to person and from firm to firm. That is, dense locations, such as cities, encourage knowledge spillovers, thus facilitating the exchange of ideas that underlies the creation of new goods and new ways of producing existing goods.

Cities and their dense inner-ring suburbs play an important role in the "new economy." In the not-too-distant past, the national economy was based on the production of goods. At the time, cities were good locations for firms because the production of goods was more efficient inside cities than outside them.[1] But manufacturing activity has continually shifted from dense to less dense parts of the country. Consequently, today, our densest cities are important not as centers of manufacturing but as centers of innovation. As economist Janice Madden has pointed out: "To the extent that there is a 'new economy,' it can be described as one in which creativity has become more important than the production of goods." Economist Leonard Nakamura has demonstrated that during the past century, increasingly more workers were "employed in creative activities such as designing, inventing, and marketing new products, and more and more economic activity [was] devoted to creating technical progress."[2] Data from the U. S. Patent Office show that annual applications for patents increased dramatically between the mid-1980s and the mid-1990s. In fact, as we'll see later, most of the patents granted in the 1990s originated in metropolitan areas.

As far back as 1890, Sir Alfred Marshall described cities as "having ideas in the air." In earlier times, cities and their environs contributed to economic efficiency when the economy was based on the production of goods. Today's cities, despite well-publicized drawbacks such as congestion, contribute to the efficient production of knowledge in the new economy.

**Jerry Carlino** is an economic advisor in the Research Department of the Philadelphia Fed.

[1] See my 1987 article for details on how cities increase productivity for manufacturing firms.

[2] Leonard Nakamura (2000) shows that in 1900, slightly more than eight of 10 workers produced goods and services. By 1999, the share had steadily declined to slightly more than four of 10.

## TWO TYPES OF KNOWLEDGE SPILLOVERS

Economists have identified two types of knowledge spillovers thought to be important for innovation and growth: MAR spillovers and Jacobs spillovers.

**MAR Spillovers.**[3] In 1890 Alfred Marshall developed a theory of knowledge spillovers that was later extended by Kenneth Arrow and Paul Romer — hence, the name MAR spillovers. According to this view, the concentration of firms in the *same industry* in a city helps knowledge travel among firms and facilitates innovation and growth. Employees from different firms in an industry exchange ideas about new products and new ways to produce goods: the denser the concentration of employees in a common industry in a given location, the greater the opportunity to exchange ideas that lead to key innovations.

Often, the latest information about technological and commercial developments is valuable to firms in the same industry, but only for a short time. Thus, it behooves firms to set up shop as close as possible to the sources of information. For example, many semiconductor firms have located their research and development (R&D) facilities in Silicon Valley because the area provides a nurturing environment in which semiconductor firms can develop new products and new production technologies.

Sometimes, information about current developments is shared informally, as has happened in the semiconductor industry. In her 1994 book, AnnaLee Saxenian describes how gathering places, such as the Wagon Wheel Bar located only a block from Intel, Raytheon, and Fairchild Semiconductor, "served as informal recruiting centers as well as listening posts; job information flowed freely along with shop talk." Other examples of "high-tech hot spots" include the Route 128 corridor in Massachusetts, the Research Triangle in North Carolina, and suburban Philadelphia's biotechnology research and medical technology industries.

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Examples of knowledge spillovers are not limited to the high-tech industry or to the United States. The geographic concentration of the motion picture industry in Los Angeles offers a network of specialists (directors, producers, scriptwriters, and set designers), each of whom focuses on a narrow aspect of movie-making. This network allows easier collaboration, experimentation, and shared learning among individuals and firms. In the medical field, research facilities and teaching institutions have concentrated along York Avenue on Manhattan's Upper East Side, home to Memorial Sloan-Kettering Cancer Center, Rockefeller University and Hospital, and New York Presbyterian Medical Center. Again, this proximity enhances knowledge spillovers among researchers at these institutions.

There are examples of knowledge spillovers in other countries, as well. Economist Michael Porter has cited the Italian ceramics and ski boot industries and the German printing industry, among others, as examples of geographically concentrated industries that grew rapidly through the continual introduction of new technologies.

**Jacobs Spillovers.** In 1969, Jane Jacobs developed another theory of knowledge spillovers. Jacobs believes that knowledge spillovers are related to the *diversity* of industries in an area, in contrast to MAR spillovers, which focus on firms in a common industry. Jacobs argues that an industrially diverse urban environment encourages innovation because it encompasses people with varied backgrounds and interests, thereby facilitating the exchange of ideas among individuals with different perspectives. This exchange can lead to the development of new ideas, products, and processes.

As John McDonald points out, both Jane Jacobs and John Jackson have noted that Detroit's shipbuilding industry was the critical antecedent leading to the development of the auto industry in Detroit. In the 1820s Detroit mainly exported flour. Because the industry was located north of Lake Erie along the Detroit River, small shipyards developed to build ships for the flour trade. This shipbuilding industry refined and adapted the internal-combustion gasoline engine to power boats on Michigan's rivers and lakes.

As it turned out, the gasoline engine, rather than the steam engine, was best suited for powering the automobile. Several of Detroit's pioneers in the automobile industry had their roots in the boat engine industry. For example, Olds produced boat engines, and Dodge repaired them. In addition, a number of other industries in Michigan supported the development of the auto industry, such as the steel and machine tool industries. These firms could produce many of the components required to produce autos.

## LOCAL COMPETITION

In addition to spillovers, economists have debated the effects of

[3] Edward Glaeser, Hedi Kallal, Jose Scheinkman, and Andrei Shleifer, who coined the term MAR spillovers, pulled together these various views on knowledge spillovers in their 1992 article.

competition on the rate of innovation and growth: some say more competitive markets innovate faster, and others argue that monopoly encourages innovation. In a classic article in 1961, Benjamin Chinitz contrasted Pittsburgh, which, at the time, was heavily specialized in a few industries and dominated by large plants and firms, with New York City's more diverse and competitive industrial structure. Chinitz suggested that because cities such as Pittsburgh have fewer entrepreneurs per capita, they produce fewer innovations than cities such as New York.

Similarly, Jacobs also believes that the rate of innovation is greater in cities with competitive market structures. According to her, local monopolies stifle innovation whereas competitive local environments foster the introduction of new methods and new products.

In addition, Michael Porter has stated that when local economies are competitive, the innovations of local firms are rapidly adopted and improved by neighboring firms. In contrast, local monopolists tend to rest on their laurels rather than risk innovation.

Alternatively, according to Glaeser and co-authors, the MAR view predicts that local monopoly is superior to local competition because innovating firms recognize that neighboring firms may imitate their ideas without compensation. Therefore, firms in locally competitive environments may invest less in research and development because they do not reap the full benefit of such investment. Thus, local monopoly may foster innovation because firms in such environments have fewer neighbors that will imitate them.

## WHAT'S THE EVIDENCE?

In 1991 Paul Krugman noted the difficulty of measuring knowledge spillovers: "Knowledge flows are invisible; they leave no paper trail by which they may be measured and tracked." In a 1993 study, however, Adam Jaffe, Manuel Trajtenberg, and Rebecca Henderson pointed out that "knowledge flows do sometimes leave a paper trail" in the form of patented inventions. Thus, studies of the importance of knowledge spillovers on local inventiveness have relied on patent data. While data on patents imperfectly reflect innovation, they may be the best available measure of inventiveness.[4] For an invention to be patented, it must be useful and novel, and it must represent a significant extension of existing products.[5]

Observing the location of patent originations leads to an important finding: patenting is largely a metropolitan phenomenon. During the 1990s, 92 percent of all patents were granted to residents of metropolitan areas, although only about three-quarters of the U.S. population resides in metropolitan areas.[6] San Jose, California, ranked first both in the number of total patents awarded and in patents per capita. During the 1990s, the San Jose metropolitan statistical area (MSA) averaged almost 18 patents for every 10,000 people, compared with 2.5 patents for every 10,000 people nationally (see Table).[7] The Philadelphia MSA ranked seventh in total patents awarded during the past decade, but only 71st in the number of patents per capita (only three patents per 10,000 people — but that's still 20 percent higher than the national average).[8]

Historical data also show that patent originations are concentrated in cities. In 1966, Allen Pred examined U.S patent data for the mid-19th century and found that patent activity in the 35 principal cities at that time was four times greater than the national average. In 1971 Robert Higgs found that the number of patents issued in the U.S. during the period 1870-1920 was positively related to the level of urbanization.

Among the information contained in a patent are references or citations to previous relevant patents. An examiner at the U.S. Patent and Trademark Office determines which citations a patent must include. For example, if a new patent cites a previous one, that indicates that the older patent contains information on which the newer patent has built. Jaffe, Trajtenberg, and Henderson looked at the propensity of new patents to cite patents that had originated from the same location. They found that a new patent is five to 10 times more likely to cite patents from the same metropolitan area than one would expect, even after eliminating those that are from the same firm. They also found that location-specific information spreads out slowly, making geographic access to that

[4] Some innovations are not patented, and patents differ enormously in their economic impact. Nonetheless, patents are a useful measure of the generation of ideas in cities.

[5] See Robert Hunt's article for a succinct review of the patenting process.

[6] The geographic distribution of patents is based on the residence of the inventor whose name appears first on the patent and not the location of the inventor's employer.

[7] MSAs are statistical constructs used to represent integrated labor-market areas that consist of counties containing a central city of at least 50,000 people along with any contiguous counties if such counties meet certain economic criteria. See the article by Bronwyn Hall and Rosemary Ziedonis for an examination of the patenting behavior of 95 U.S. semiconductor firms during the period 1979-95.

[8] Maryann Feldman and David Audretsch used the U.S. Small Business Administration's innovation database, which consists of innovations compiled from new product announcements in manufacturing trade journals. They found that in 1982 only 150 of the innovations (4 percent) covered by their data set occurred outside of metropolitan areas. Almost one-half of all innovations occurred in four metropolitan areas: New York (18.5 percent), San Francisco (12 percent), Boston (8.7 percent), and Los Angeles (8.4 percent).

knowledge important to firms. They took these findings as evidence of knowledge spillovers in metropolitan areas.

**Estimating the Effect of Urban Density on Patenting.** While economists believe that denser areas promote knowledge spillovers that foster innovations, past studies have not looked at the relationship between density and innovation. To investigate this relationship, we need a measure of local employment density. Employment density varies enormously within an MSA. Typically, employment density is highest in the central business district (CBD) of an MSA's central city and generally falls off as we move away from the CBD. An urbanized area is defined as the highly dense area within an MSA.[9] If knowledge spillovers are important, it's likely that urbanized areas with high-employment density would account for most of them.

So ideally, we want to use employment density in the urbanized area of the MSA to investigate the relationship between density and innovation. While we can measure the size of the urbanized part of an MSA, employment data are not available for urbanized areas of MSAs. So we used two alternative measures for local employment density. Our first measure for local employment density assumes that all employment in an MSA is located within the MSA's urbanized area. This assumption means that our first measure overstates both employment and local employment density. Our second measure is the ratio of employment in the county containing the MSA's central city to square miles in the urbanized area of the MSA. Since the urbanized area is defined to include the MSA's central city *and* the highly dense surrounding areas, our second measure understates both employment and employment density in urbanized areas. By using these alternative measures for local employment density, we believe that the two estimates of the effect of local employment density on the rate of patenting obtained in our

[9] The Census Bureau defines an urbanized area as one with a total population of at least 50,000, consisting of at least one large central city and a surrounding area with a population density greater than 1000 people per square mile.

## TABLE

### Top 50 MSAs' Per Capita Patent Activity in the 1990s

| MSA Name | Patents per 10,000 People In the MSA | MSA Name | Patents per 10,000 People In the MSA | MSA Name | Patents per 10,000 People In the MSA |
|---|---|---|---|---|---|
| San Jose, CA | 17.6 | Minneapolis, MN | 5.7 | Santa Barbara, CA | 4.2 |
| Boise City, ID | 14.1 | Santa Cruz, CA | 5.6 | Hamilton, OH | 4.2 |
| Rochester, NY | 13.0 | Albany, NY | 5.5 | San Diego, CA | 4.1 |
| Boulder, CO | 11.2 | Raleigh, NC | 5.5 | New Haven, CT | 4.1 |
| Trenton, NJ | 10.5 | Brazoria, TX | 5.2 | Portsmouth, NH | 4.1 |
| Burlington, VT | 9.0 | Manchester, NH | 5.2 | Lafayette, IN | 4.0 |
| Rochester, MN | 9.0 | Boston, MA | 5.1 | Rockford, IL | 4.0 |
| Poughkeepsie, NY | 8.8 | Binghamton, NY | 5.1 | Cincinnati, OH | 3.9 |
| Ann Arbor, MI | 8.3 | Newark, NJ | 4.5 | Hartford, CT | 3.8 |
| Austin, TX | 8.0 | Kokomo, IN | 4.5 | Monmouth-Ocean, NJ | 3.8 |
| Middlesex, NJ | 7.7 | Madison, WI | 4.5 | Akron, OH | 3.8 |
| Wilmington, DE | 7.5 | New London, CT | 4.4 | Allentown, PA | 3.8 |
| Lake County, IL | 7.1 | Oshkosh, WI | 4.4 | Greeley, CO | 3.8 |
| Saginaw Bay, MI | 7.0 | Anaheim, CA | 4.4 | Seattle, WA | 3.8 |
| Ft. Collins, CO | 7.0 | Cedar Rapids, IA | 4.3 | Kalamazoo, MI | 3.8 |
| Bridgeport, CT | 6.7 | Elmira, NY | 4.3 | Sheboygan, WI | 3.8 |
| San Francisco, CA | 5.8 | Oakland, CA | 4.2 | | |

analysis will capture the true effect of density on innovation.[10]

Data for the 1990s on 270 MSAs reveal a positive association between patents per capita and local employment density.[11] But, as we just discussed, other characteristics of the local economy (such as its industrial structure and its competitiveness) can also affect the number of patents. A standard statistical technique, called multiple regression analysis, can be used to identify the factors that best explain MSA differences in patents per capita. We considered the effects of a wide range of factors — such as the number of employed people in the MSA (or MSA employment), R&D spending in science and engineering programs at colleges and universities (university R&D), the share of large firms (1000 or more employees), and educational attainment of the population — on patents per capita in metropolitan areas to determine how the number of patents per capita during the 1990s was affected by metropolitan employment density in 1989 (see the Appendix).

**Density.** During the 1990s, patenting was significantly greater in MSAs with denser local economies. For example, the number of patents per capita was, on average, 20 percent to 30 percent higher in an MSA whose local economy was twice as dense as that of another MSA. Since local employment density varies by more than 2000 percent across locations in the sample, the implied gains in patents per capita due to urban density are substantial. For example, in 1989, the average urbanized area in our sample had about 1500 jobs per square mile (assuming all jobs in the MSA are located inside its urbanized area). Toledo, Ohio; Eugene, Oregon; and Omaha, Nebraska are three MSAs with local employment density at about this average level. These three MSAs averaged 1.8 patents per 10,000 people during the 1990s. If their local employment density were to double, the statistical model predicts that patents would rise, on average, to 2.3 per 10,000 people. Thus, these findings are consistent with the widely held view that the nation's densest locations — its central cities and their dense inner-ring suburbs — play an important role in creating the flow of ideas that generate innovation and growth.

Before we can reach a definitive conclusion, we must remember that the rate of patenting may be greater in denser locations for reasons other than knowledge spillovers.

However, before we can reach a definitive conclusion, we must remember that the rate of patenting may be greater in denser locations for reasons other than knowledge spillovers. For example, it's possible that in urban areas it's harder to keep information secret, so firms resort to patents. Wesley Cohen, Richard Nelson, and John Walsh examined this possibility in a study, referred to as the Carnegie Mellon Survey (CMS), which was based on a 1994 survey of R&D at 1478 manufacturing firms. Results of the CMS show that manufacturing firms typically protect the profits from their innovations with a variety of mechanisms, including patents, secrecy, and first-to-market advantages. Furthermore, the majority of manufacturing firms surveyed indicated that they rely on secrecy and first-to-market advantages more heavily than patents.

More important for our purposes, surveyed firms indicated that concern over information disclosed in patents is a major reason many choose not to pursue a patent. Current laws require patents to describe an invention in precise terms. In addition, there are high fixed costs associated with preparing a patent application (such as legal fees and the cost associated with patent searches). Secrecy, however, avoids these fixed costs, but preventing disclosure of secret information incurs expenses. Although the CMS does not consider the location of the firms in its sample, its findings nonetheless suggest that firms may be forced to rely on patenting to a greater extent in dense areas because it is harder and more costly to maintain secrecy there than in less dense areas. Thus, it may be this increased difficulty in maintaining secrecy, and not knowledge spillovers, that accounts for the positive correlation between patents per capita and metropolitan density.

Unfortunately, we cannot distinguish between the effects of knowledge spillovers and those of secrecy in our empirical model.[12] While the inability to maintain secrecy in dense locations may account for some portion of the positive association between patents per capita and density, it is unlikely that it would completely "crowd out" the effects of knowledge spillovers.

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[10] See the Appendix for details on how the local employment density variables are constructed.

[11] The simple correlation between the logarithm of patents per capita and the logarithm of local employment density is moderately positive (0.50) and statistically significant.

[12] At this time, data that would allow us to discern the role of knowledge spillovers and that of secrecy in patent activity in dense local areas are not publicly available.

**Industrial Specialization.** Even if we accept the view that dense local areas serve as centers for the exchange of ideas, we come back to the issue of whether the rate of exchange is enhanced in industrial environments that are diverse (for example, New York City) or in more specialized ones (for example, Silicon Valley). Feldman and Audretsch's 1999 study, which used the U.S. Small Business Administration's innovation database, focused on innovative activity for particular industries within specific MSAs. They found less industry-specific innovation in MSAs that specialized in a given industry, a finding that supports Jane Jacobs' diversity thesis. Glaeser and co-authors provided indirect evidence by looking at employment growth between 1956 and 1987 across specific industries in a given city. They found that industrially diversified areas grew more rapidly than specialized areas.

Conversely, in our empirical work, we found little evidence that diversity, or the lack of it, was an important factor in determining the rate of patenting activity in metropolitan areas in the 1990s.

**Competition.** Finally, we look at the evidence on whether the creation of ideas is greater in competitive local environments characterized by many small firms than in local economies dominated by a few large firms. Feldman and Audretsch found that local competition is more conducive to innovative activity than is local monopoly. More indirect evidence on this issue is offered by Glaeser and co-authors' finding that local competition is more conducive to city growth than is local monopoly. Counter to these studies, and to the views of Chinitz and Jacobs discussed earlier, our empirical findings show that, overall, patenting is not related to local competition or the lack of it.[13]

In sum, our findings suggest that the high concentration of people and firms in cities fosters innovation and, along with the findings of other studies, offer little support for the MAR view that specialization and local monopoly foster innovation. The evidence is mixed on Jacobs' view: While we find little evidence that the rate of innovation is greater in diverse and locally competitive environments, studies by Glaeser and co-authors and by Feldman and Audretsch, however, report results favorable to this view.

## CONCLUSION

The extraordinary recent growth in productivity and jobs in the United States has been attributed in part to innovation. The empirical work we discuss in this article has shown that patent activity is positively related to the density of an MSA's highly urbanized area (the portion containing the central city). Our findings suggest that dense urban areas, such as central cities, foster knowledge spillovers, which are important in the generation of new ideas that lead to new products and new ways to produce existing products.

Given the role that dense geographic locations may play in promoting innovation, the postwar decline of the nation's dense central cities relative to their less dense suburbs should be a concern to both local and national policymakers. In fact, in a 1997 study, Joe Gyourko and Dick Voith showed that many central cities have experienced not only declines in economic activity relative to their suburbs but absolute declines as well. Sound urban policies are necessary to make the most of the growth potential that the central cities of the nation's metropolitan areas offer. But local and national policies have often contributed to the suburbanization of jobs and lowered the employment density of central cities. In doing so, they may have weakened the economy's ability to innovate and may ultimately lead to slower growth. BR

[13] In our empirical model, we examine the rate of local patenting and a number of other characteristics of the local economy (such as the level of employment in an MSA, the relative importance of large firms in an MSA, the percent of total MSA employment in manufacturing, and the percent of an MSA's population with a college education). The level of MSA employment, the relative importance of large firms in an MSA, the percent manufacturing in an MSA, and the percent college educated in an MSA were associated with significantly higher rates of MSA patenting during the 1990s (see the Appendix for details).

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# APPENDIX

The variables that were considered in the empirical model are those thought to affect patenting at the MSA level, as discussed in the text.[a]

$\ln(\text{Patents per Capita}_i) = C + a_1 \ln(\text{MSA Employment}_i) + a_2 \ln(\text{Employment Density}_i) + a_3 \ln(\text{University R\&D}_i)$
$+ a_4 \text{Large Firms}_i + a_5 \text{Manufacturing Share}_i + a_6 \text{College Educated}_i + a_7 \ln(\text{IndustrialSpecialization}_i) + a_8 \ln(\text{Competition}_i)$
$+ a_9 \text{Employment Growth}_i$

where

Patents per $\text{Capita}_i$ = Patents per capita, annual average for the period 1990-99 in MSA i

MSA $\text{Employment}_i$ = 1989 level of private nonfarm employment in MSA i

Employment $\text{Density}_i$ = The density of employment in 1989 in the ith MSA's urbanized area
Two alternative measures are used: in model (1) employment density = MSA employment divided by square miles in the MSA's urbanized area; in model (2) employment density = employment in the county containing the MSA's central city divided by square miles in the urbanized area.

University $\text{R\&D}_i$ = University R&D spending in science and engineering programs, annual average for the period 1989-91 in MSA i

Large $\text{Firms}_i$ = Percent of firms with 1000 or more employees in 1989 in MSA i

Manufacturing $\text{Share}_i$ = Manufacturing share of total employment in MSA i, in 1989

Percent College $\text{Educated}_i$ = Percent of 1990 population with at least a college degree in MSA i

Industrial $\text{Specialization}_i$ = the Herfindahl index = $\sum_{J=1}^{7} (s_{j,\,i})^2$, where $s_{j,\,i}$ is the share of employment in industry *j* in MSA i

$\text{Competition}_i$ = Total number of firms in MSA i divided by total employment in MSA i

Employment Growth $\text{Rate}_i$ = employment growth rate in MSA i during the period 1979-89.

The dependent variable refers to patents per person in the MSA averaged over the period 1990-99, whereas the independent variables are at 1989 or roughly beginning-of-the-period values. This reduces the simultaneity and reduces concerns about direction-of-causation issues, since the value of the dependent variable that is averaged over the 1990s is not likely to affect beginning-of-period values of the independent ones. Employment size in 1989 is included because other researchers have found that innovative activity increases with MSA size.

Research and development (R&D) spending in science and engineering programs at colleges and universities is included separately, since many authors have found spillovers from such spending and innovative activity at the local level. Similarly, since large firms tend to spend proportionately more on private R&D than do smaller firms, the percentage of an MSA's firms with 1000 or more employees is included separately to capture the presence of large firms on patent activity. The percent of an MSA's population with at least a college degree is included to separately account for the role of educational attainment in patenting.

The share of MSA employment accounted for by each of seven industries is used to calculate the Herfindahl index of industry specialization.[b] Squaring each industry's share of employment, $s_i$, means that larger industries contribute more than proportionately to the overall value of the index. Thus, as the index increases in value for a given MSA, this implies that the MSA is more highly specialized or less diversified industrially. Following Glaeser et al. (1992), we use the total number of firms per worker in an MSA as a measure of competition; that is, an MSA is taken as locally competitive if it has many firms per worker. Finally, employment growth during the period 1979-89 is included to control for any independent effect that local growth may have had on patent activity.[c]

[a] For additional details, see the working paper by Carlino, Chatterjee, and Hunt.

[b] The seven industries are manufacturing; transportation, communications, and public utilities; wholesale trade; retail trade; services; finance, insurance, and real estate; and other industries. Construction's share of private nonfarm employment was not included in the calculation of the index because of disclosure problems associated with this variable for some MSAs in our sample.

[c] We included dummy variables in both versions designed to see if specific regions of the country contributed more or less to MSA patenting. Each MSA was classified into one of eight broad regions (New England, Mideast, Great Lakes, Plains, Southeast, Southwest, Rocky Mountain, and Far West). We found that MSA patents were higher in the Mideast and Great Lakes regions relative to the Southeast region; the coefficients for the other regions were not statistically significant.

## APPENDIX

The model was estimated using ordinary least squares methods with White robust standard errors to take heteroskedasticity into account.

As indicated in the text, one problem is that employment data for urbanized areas are not available. Therefore, we must estimate it. In model (1) we assume that all employment in an MSA is located within its urbanized area. This assumption overstates both employment and employment density in urbanized areas. In model (2) we assume that all employment in an MSA is located within the county that contains the MSA's central city. This assumption understates both employment and employment density in urbanized areas.[d]

[d] On average, the county containing an MSA's central city accounts for 84 percent of MSA employment.

The results of the regression are presented in the table on the next page. As the results of both models show, the effect of employment density on patenting is positive and highly significant. These findings suggest the importance of close spatial proximity in promoting spillovers and fostering innovation. A number of other variables in the model have the expected positive association with the rate of MSA patenting, including MSA employment size, percent of MSA firms with 1000 or more employees, percent of MSA employment in manufacturing, and the percent of MSA population with a college education. The coefficient on the Herfindahl index is not statistically significant, suggesting that an MSA's degree of industrial specialization does not have a significant impact on MSA patenting. Similarly, the variable firms per employee is not significant, suggesting that competitiveness of the local economy does not appreciably affect MSA patenting activity. One anomaly is that university R&D spending has the wrong sign (negative, which suggests that increased spending by local universities on R&D in science and engineering programs is associated with fewer patents per capita in an MSA), but it is not significant. Finally, the $R^2$ statistic, measuring the goodness of fit, shows that the models explain a little more than 60 percent of the variation in MSA patents per capita (this is a good fit for a cross-MSA model).

## APPENDIX TABLE

### The Determinants of Patents Per Capita[a]

| | (1)[b] | (2)[c] |
|---|---|---|
| Urbanized area employment density (MSA employment) | 0.3058** | |
| Urbanized area employment density (central city's county) | | 0.2056** |
| 1989 Employment | 0.2985** | 0.3368** |
| University R&D spending | -0.0086 | -0.0102 |
| Percent of firms with 1000 or more employees | 202.1* | 227.9** |
| Percent mfg. | 3.66** | 4.12** |
| Percent college educated | 6.63** | 6.60** |
| Herfindahl index | 1.4785 | 1.8249 |
| Firms per employee | 0.5298 | 0.5654 |
| Employment growth, 1979-89 | 0.1018 | 0.1253 |
| Constant | -13.8** | -13.1** |
| No. of Obs. | 270 | 257 |
| $R^2$ | 0.6138 | 0.6169 |

* and ** indicate statistically significantly different from zero at 5 percent and 1 percent levels, respectively.

[a] Both models include a set of dummy variables to account for the MSA's region.

[b] In model (1) employment density = MSA employment divided by square miles in the MSA's urbanized area.

[c] In model (2) employment density = employment in the county containing the MSA's central city divided by square miles in the MSA's urbanized area.