Joseph L. Rotman School of Management
University of Toronto

Rotman

**The Martin
Prosperity Institute**

Beyond Spillovers:

The Effects of Creative-Density On Innovation

Brian Knudsen, Richard Florida and Kevin Stolarick

September 2005

Abstract: The productivity enhancing capability of cities is widely noted. Yet, while urban innovative capacity is often assumed to arise due to the close proximity of diverse elements within cities, little empirical research has attempted to associate population density with urban innovation. Thus, this research investigates how the density of a specific class of workers, the "creative class", affects metropolitan innovation. It builds upon, extends, but in important ways departs from studies linking innovation to geographically mediated knowledge spillovers. Multivariate analyses suggest that density and creativity separately and jointly affect innovation in metropolitan areas. Keywords: *Creativity, Density, Innovation, Learning, Spillovers*

I. Introduction

In this article, we take a fresh look at the geographical determinants of innovation, doing so by examining density, and more specifically the density of creativity, as a key factor influencing metropolitan area innovation. Density has become a topic of increasing interest to scholars studying the factors that influence regional innovation and growth. This article builds upon this recent attention while also extending the existing literature on the determinants of regional innovation in a number of important ways, foremost by focusing on the relationship between innovation outcomes and the interaction of highly skilled individuals and population density. In doing so, we expand upon, and in some important ways depart from, the inter-related concepts of proximity, knowledge spillovers, and face-to-face interactions of intellectual human capital often discussed in recent economic geography literature. A few recent papers have begun to explore the relationship between forms of density and the production of new knowledge. For example, at the state level, Ciccone and Hall (1996) find that employment density increases average labor productivity, while Sedgely and Elmslie (2004) find a positive relationship between state population density and innovation. At the city level, Strumsky, Lobo, and Fleming (2005) positively link population density to metropolitan patenting, while working papers by Carlino, Chaterjee, and Hunt (2001, 2005) demonstrate the positive role of local employment density on innovation. Building upon some of these recent articles, in our analyses we employ population density at the metropolitan level. Yet, we extend beyond them by combining our use of population density with the recent research demonstrating the positive effects of human capital on innovation to posit that high densities of human capital workers promote innovation. More specifically, we utilize Richard Florida's creative capital theory (2002c) to claim that it is the density of not only human capital but of those whose occupations have a creative component that are primarily responsible for urban innovation and subsequently growth.

Additionally, establishing and understanding the reasons for a link between density and innovation allows policies to emerge that promote both. To know how to promote density, we must know why people value it and what about it they value. Ultimately, this reduces to having a firmer understanding of people's location decisions and the factors influencing them. This understanding points to the broad research thrust directing this particular study. Specifically, that thrust is to examine why people and firms make particular location decisions. Relating this broad framework to the research at hand, we posit that creative, educated working people will choose to live and work in those locations that enable them to improve upon and take as great advantage of their skills as possible. In essence, they hope to locate in a place that will make them more productive. Thus, we might conclude that they would value dense environments, to the extent that such places promote learning, exchange of knowledge, and gains to their own productivity and skills. Also, to the extent that they are aware of this effect, density can be a factor inducing them to locate. Yet, before we are able delve deeper into these issues in future research, we first need to empirically demonstrate the link between density and innovation. Glaeser (2000, 105) describes this broad thrust by saying: "[t]he central question of urban economics – namely, *Why do cities exist?* – can only be answered by understanding the effects of cities on their residents. And to understand what determines the demand for it, we must understand what urban density does."

We posit that the learning and returns to one's skills and creativity facilitated by density-induced interactions will lure people to cities. Furthermore, implicit in Florida's creative capital theory is that these interactions do not occur in a vacuum, but that a social structure must be in place enabling their occurrence. This social structure provides a setting and framework for these interactions, while also reinforcing people's creative identities and supporting and fostering norms and attitudes that promote creativity and growth. Thus, a creative person would locate in a dense place to the extent that she could anticipate returns to her skills and creativity, but also to the extent that a creative social structure was in place that provided the necessary setting for these interactions to occur in the first place.

Finally, probing the link between density and innovation is an interesting exercise on its own, due to the value society places on innovation, and to how we often positively associate it with increasing social welfare. The connection between innovation and the promotion of social welfare is well understood and equally well documented. In her seminal book The Economy of Cities, Jane Jacobs (1970, 49) connects innovation and growth when she claims that "Innovating economies expand and develop. Economies that do not add new kinds of goods and services, but continue only to repeat old work, do not expand much nor do they, by definition develop". Glaeser (2000, 83) views cities as centers of idea creation and transmission and figures that "cities will grow when they are producing new ideas or when their role as intellectual centers is increasing". Finally, Paul Romer (1990) and other new growth theorists cite innovation as a key factor in economic development. Thus, given the correspondence between innovation and sought social outcomes, it remains to identify the causal factors that bring about innovation.

We proceed with a concepts and theory section that first examines the existing research that to date looks into the geographical determinants of innovation, then briefly suggests how a testable theory arises from it, and subsequently examines this hypothesis in greater detail. We then discuss the data, methodologies, results, conclusions, and policy aspects of the findings.

II. Concepts and Theory

Concepts:

The theory tested in this study is a logical progression from the recent literature examining the geographic determinants of innovation. This literature is, in part, based upon the "knowledge production function" approach introduced by Griliches (1979). The typical economic production function examines the effects of particular inputs on the production of outputs. In this vein, the knowledge production function considers the effects of such typical inputs as R&D expenditures and human capital on such outputs as economic growth, productivity, or innovation. Griliches (1979, 93) regards

> …total output or total factor productivity as a function of past R&D investments (and other variables). Here *all* productivity growth (to the extent that it is measured correctly) is related to *all* expenditures on R&D and an attempt is made to estimate statistically the part of productivity growth that can be attributed to R&D (and sometimes, also, to its components).

The existence of increasing returns to knowledge producing inputs in the knowledge production function is indicative of knowledge spillovers (defined by Griliches (1992, 36) as "working on similar things and hence benefiting much from each other's research") because the R&D undertaken by particular agents can be taken up or used by other agents to improve or promote innovations by the other firms. The social benefit to undertaking the inputs would be greater than the benefits that would accrue to any one individual or firm, thus indicative of spillovers.

Existing literature has demonstrated the links between knowledge producing inputs, outputs, and knowledge spillovers (Jaffe 1986) noting that a significant fraction of spillovers affecting a firm's innovative activity come from other firms. According to Feldman (2000), demonstrating that knowledge can spill across firms at all, especially across firms in close technological proximity, means that there is a credible possibility that geographic proximity can also mediate these spillovers. Thus, recent literature has added a geographic element to the knowledge production function in an attempt to measure "the geographic impact of knowledge spillovers on innovation" (Feldman 2000).

A study by Audretsch and Feldman (1996) presents key findings in this line of research. They note that an important result of previous research is that the R&D investments of private corporations and universities spill over to third parties. If the ability to receive knowledge spillovers depends on distance from the knowledge source, then clustering of knowledge producing inputs (R&D expenditures, human capital, etc) should ensue. It follows that the innovative activity should also cluster, following the clustering of the inputs. Conversely, if we observed a more evenly spread pattern of innovation, it would imply that knowledge spillovers are not geographically mediated. The authors find that, even after controlling for the concentration of production, innovation is still concentrated close to the source of the new knowledge. This provides evidence that the spillovers have a geographic limitation. Glaeser (2000, 103) provides intuition for this effect when he notes that "The [externality] kind of [non-market] interaction even more strongly depends on spatial proximity. In many cases, these effortless transmissions of ideas and values depend on sight or hearing…. Obviously, the ability to see or hear depreciates sharply with space". The important insight from this strain of research is to show that the geographic proximity of knowledge producing inputs influences the knowledge flows that are responsible for innovation. But, there is little empirical attention given to the mechanisms that produce the spillovers, and also, importantly for our research, little attention given to specific conceptions of proximity like density. We next describe literature that looks into these mechanisms promoting spillovers, and subsequently explain how the current work will build upon the previous literature.

Zucker, Darby, and Brewer (1998) demonstrate how intellectual human capital is a means by which geographically mediated spillovers are realized. They empirically demonstrate how the localization of intellectual human capital (embodied in "star" bio-technology scientists) is predictive of the localization of new bio-tech start-up firms. Feldman (2000, 380-1) claims that "[t]his work demonstrates that localized intellectual capital is key in the development of the bio-tech industry and that knowledge generates externalities that tend to be geographically bounded within the region where the scientists reside". Thus, whereas the first strain of literature demonstrated that geographic proximity is important in that it promotes the spillovers necessary for innovation, this research suggests that the skills and knowledge embodied in individuals are the mechanisms by which these spillovers actually occur. Lucas (1988) and Storper and Venables (2004) take this one step further by reasoning that it is the face-to-face interactions between individuals with high human capital that facilitates spillovers and the growth of knowledge. Lucas continues by saying that these interactions are so important that people are willing to pay extremely high land rents in order to be close to other people, and thus to benefit in terms of learned knowledge and increased productivity.

Thus, to summarize, the knowledge transmission and learning preceding innovation is geographically bounded if, given the tacit nature of the knowledge often responsible for innovation, the knowledge producing sources must be proximate to enable the spillovers to occur. The mechanism enabling these spillovers to occur is the intellectual human capital and knowledge embodied in individuals, and specifically, according to Lucas and others, the interactions amongst these individuals.

<u>Theory:</u>

A hypothesis arising from this literature is that the geographic proximity of individuals possessing human capital, skills, expertise, or creative capabilities enables their interactions, and these interactions facilitate the spillovers necessary for innovation. To date, such a theory has not been sufficiently empirically tested in the literature except for in a recent working paper using French data by Autant-Bernard and Messand (2001). However, our analysis differs from theirs in that we examine population density as a specific conception of geographic proximity. We feel population density better describes the geographic closeness of people than previous conceptions of proximity and provides better intuition as to why the interactions between them occur. The role of density is more fully described below. Also, our approach differs from previous density research in that we consider the effect of a specific form of density, namely the density of "creative capital". To date, no research has examined how the density of Richard Florida's creative class is related to innovation. The creative class consists of workers "whose economic function is to create new ideas, new technology, and/or new creative content", such as scientists and engineers, architects, designers, artists of all sorts, and educators (Florida 2002c, 8). Since innovation is an inherently creative act and not only traceable to those who meet a certain educational threshold, we feel creative capital offers more precision than the use of education-based human capital measures. Highly creative and innovative people – like Bill Gates – are included in the creative class, whereas they would be excluded from human capital measures. Additionally, as discussed above, we make use of population density measures instead of more commonly employed employment density measures. This too derives in part from Florida's characterization of the creative class. Individuals do not leave their creativity, the core element of the economy, behind in the lab, studio, office, or university when they finish their workday. Instead, the creative class is always creatively engaged, and seeks to reinforce their identities as creative people in all aspects of their lives, from consumption, to recreation habits, to interpersonal relationships. Thus, regions that are broadly appealing to the creative class are best situated for growth. So, innovation and growth are not singularly institutionally or firm focused, and our use of a broader population density measure is an attempt to capture that. We propose one primary hypothesis that reflects and fine-tunes the concepts outlined above and that we will empirically test: *High densities of creative capital leads to and makes frequent face-to-face interactions amongst them, thus facilitating "creative" spillovers, and subsequently innovations*[1].

Until now, we have discussed in detail how geography, human capital and creativity, and interactions relate to spillovers and learning, but we have not described specifically how these various factors (spillovers included) relate to innovation. To do so, and thus to also be able to examine our hypothesis in more detail, we must define innovation, and present general notions of how it is theorized to arise.

In The Economy of Cities, Jacobs (1970) defines innovation as the process by which new work is added to old divisions of labor, thus creating new products, processes, or ideas, and thus also new divisions of labor. Feldman (2000, 373) adds that "innovation is the novel application of economically valuable knowledge". In other words, innovation is a process of creating new, profitable products and ideas by combining observations or insights taken from elsewhere to the work one had previously been doing (Desrochers 2001, 378).

Building on this definition, innovations occur when individuals with high degrees of existing creativity or knowledge make new and novel combinations of this knowledge with new insights observed or learned through spillovers. Individuals require a high degree of existing expertise to engage in innovation for a number of reasons. First, an extensive and sophisticated knowledge of the initial work will provide insights into how to create "new combinations" when new observations arise through spillovers. Clearly, if one has a superficial knowledge of the initial work, it will be less obvious how to make interesting departures from that work or important additions to it. Cohen and Levinthal (1994) note how this phenomenon exists at the firm level, referring to a firm's ability to leverage its installed base of expertise to sift through and take advantage of the signals it receives from the outside as the firm's "absorptive capacity". Additionally, Desrochers (2001, 376) adds that "…innovation ultimately depends to some degree on one person's knowledge and skills", while Lee (2001) has empirically documented the positive effects of high human capital workers on innovation. Thus, the ideas necessary for innovation are embodied in individuals with the creativity, know-how, and skills to engage in technological advance.

Innovation occurs when a person possessing creativity combines her existing expertise with observations learned through spillovers. Such a spillover occurs when one individual's creativity is transferred to another individual or firm. These creative spillovers are in part believed to arise due to frequent face-to-face interactions and communication between individuals. Furthermore, these interactions are made more frequent by population density[2]. Also, the literature explains that geographical proximity (here conceived of as density) makes it more likely that the "tacit" (non-codified) knowledge essential to innovation and embodied in individuals will be shared through face-to-face contact. Finally, learning is facilitated when ideas are closer spatially (Howells, 2000). We extend this reasoning to conclude that it is not just frequent interactions of all people that bring about spillovers and thus innovation, and also not just high human capital workers as posited earlier. Given the inherently creative nature of innovation, we hypothesize that the density-induced frequent interactions between creatively oriented, high human capital individuals will result in the creative spillovers necessary to facilitate innovation. This reasoning also makes use of Florida's (2002c) creative capital theory, where he posits that occupations with a creative component fuel innovation and growth.

In dense cities, scientists and engineers, artists, writers, and people from all walks of life are all forced together and all rub shoulders. For the scientists and engineers, being near people of similar capabilities and expertise increases their own productivity through spillovers. They come up with ideas together that they would not have otherwise generated. Additionally, the general creative milieu of a place with a prominent presence of artists, musicians, and other creative people increases overall creativity and innovation by providing stimulus and inspiration for those who actually produce innovations. The idea is that all creative people, artists, writers, scientists and engineers, etc., work best in an environment that promotes and rewards creativity. Having the creative milieu might also act as a regional attraction for scientists and engineers. The role of population density in all of this is to compact all of these people into a space where they collide, and where these important interactions and spillovers can occur.

The next step is to empirically specify these relationships. It is very difficult to empirically capture flows of creativity or knowledge between individuals. Yet, we attempt to capture or reflect the mechanisms discussed above by considering how density affects the returns to creative capital in metro areas. We predict that metro area density will increase the impact of creative capital on innovation, and thus increasing returns to creative capital (creative spillovers) will be greater in the presence of high density. Empirically, this would mean that in an equation in which "innovation" is the dependent variable, interactions between density and creative capital would be positive, and that the effect size would be larger than an effect size for creative capital alone. A simple linear equation describes this hypothesis below.

$$\begin{aligned} Innovation &= \beta_1 + \beta_2 density + \beta_3 creativity + \beta_4 creativity * density + \beta_5 R \& D + \\ &\beta_6 Scientists / Engineers + \beta_7 bohemians + \beta_8 gays + \varepsilon \end{aligned} \quad (1)$$

As (Eq. 1) suggests, many other variables have been linked either theoretically or empirically to innovation, and we thus incorporate several of these into the analysis. First, much analysis, like that of Griliches, has been devoted to demonstrating the link between research and development expenditures (R&D) and innovation. R&D is commonly regarded as a key input in the knowledge production function, and thus necessarily needs to be taken into account in any analysis that looks to explain innovation.

Second, studies by Florida and Gates (2001), Florida (2000, 2002a, 2002b), and Lee (2001) links the presence of both bohemians (defined as artists, musicians, writers, poets, etc.) and gays to innovation. These studies find that new ideas, processes, and products arise from a multiplicity of perspectives and people, and thus the presence of gays and bohemians in regions is indicative of the tolerance needed to nurture and support this multiplicity. To account for their theory, we will also incorporate these variables into our analyses.

III. Data and Methods

Our theory is that high densities of creatively oriented workers will promote metropolitan area innovation. Thus, we will need measures of density, creativity, innovation, and other important controls [see Table 1]. The unit of analysis for this study will be the Primary Metropolitan Statistical Area (PMSA). This is a geographical area comprised of a central county and its economically related outlying territories. Census periodically redefines the component units that comprise PMSAs, and we use the 30 June 1999 definitions. We use PMSAs for several reasons. First, PMSAs capture economic spheres of influence. Second, given that this study hopes to identify relationships at a regional level, instead of at a smaller scale, the PMSA appears most appropriate[3]. Finally, note that all predictors chronologically precede the dependent variables included in the analysis.

<u>Density</u>**:** We employ several variables of population density[4]. We do this because no one measure fully captures the full "essence" of the density construct, but instead each measure reflects a different dimension. Each of the measures clearly has relative strengths and weaknesses, described below. Thus, using multiple measures and eventually combining them into a composite measure is an attempt at triangulating towards a fuller and more inclusive concept of density, and one that is more reflective of the proximity of people discussed in the theory above. Below are full documentations of each density measure.

Census Population Density: The two simplest measures are 1990 Census population / 1990 PMSA land area and 2000 Census population / 1999 PMSA land area[5]. We generated these measures by employing population data from the Census Department's website[6], and land area data from the

Census Factfinder[7] site. The population data is organized by MSA and all components – counties, towns, etc. Thus, MSA land area[8] is found by locating the component land area (usually county) on the Factfinder site, and then aggregating these up to the MSA area. This is done for all MSAs and PMSAs. We then simply divide MSA/PMSA population by the corresponding land area. Henceforth, we will refer to these measures as the Census Population Density measures.

Percent Population in Urbanized Areas: Paul Overberg (2001) of the USAToday newspaper constructed another measure that captures elements of density. This measure is the percentage of metropolitan statistical area (MSA) population in Urbanized Areas in 1990. Urbanized Areas are defined by the Census Bureau to be areas with a population density of at least 1000 people per square mile. This measure also makes use of 1990 Census data. Henceforth, this measure will be called percent in UA.

Urban Density: Several other density measures are borrowed from the July 2001 Brookings Institute Paper "Who Sprawls Most? How Growth Patterns Differ Across the U.S.", by Fulton et al. The authors compute density measures for 1982 and 1997, but instead of using just land area in the denominator, they derive acres devoted to urban uses from the National Resources Institute's national survey of land use. We subsequently convert acres to square miles. This measure, PMSA population divided by urban acres is calculated for both 1982 and 1997. Then, since we know the change in population for 1982 to 1997 and the change in urbanized acres for 1982-1997, we can divide the two, and thus calculate the "marginal density". This tells us how many people were added to the PMSA over the 15 year span for each new acre of land developed for urban use. The authors note that their measures are not simply residential densities, but instead overall densities based on all land urbanized to meet population growth[9]. Henceforth, we will refer to these measures as Urban Density 1982 and 1997.

Each density measure has strengths and weaknesses, and thus is included in the analysis for different reasons. A major strength of the Census Population Density measure is that it is conceptually simple – it provides a simple average density for each MSA, and is easy to interpret. Furthermore, given that it measures residential population density, it gives an intuitive description of the closeness of people to one another in an MSA, and thus is reflective of the above theory. Lastly, the data to construct these measures is readily available, even down to small units like tracts. Yet, Census Density has several weaknesses. First, given that the total land area for an MSA or PMSA changes very little across years, over time the variables primarily reflect population changes, even accounting for changes to MSA definitions. Also, these measures abstract out a lot of information. Specifically, they do not depict how population is distributed within an MSA, instead, often incorrectly, averaging population evenly over the entire MSA.

The Urban Density measures, along with marginal density, have distinctive strengths. First, Fulton et al's (2001) study was the first to measure metropolitan area density using an actual measurement of urban land. Given that urbanized land has been drastically increasing over time, we are more likely to observe decreases in density over time than with the Census Population Density measures if population grows at a slower rate. Clearly, these measures more closely track increases in urban lands, and show how density reacts to these changes over time. Thus, these measures are not simply charting changes in population, but instead are documenting relationships between population and land area, and doing a better job at this than Census Population Density[10]. Yet, similar to Census Population Density, these measures also are only an average density across the entire MSA/PMSA, and thus abstract out much information about how population is distributed within an MSA/PMSA.

To the extent that the Percent in UA measure defines land as urban by its ability to meet a particular residential density threshold, it once again captures the notion of the closeness of people depicted in the theory section. But, this measure is not explicitly density, but instead just a description of a minimum density. Thus, with this measure we do not even have an estimate of an average density across the whole MSA, and do not know whether most of the MSA contains densities close to the threshold, or whether segments of the MSA have densities high above it. Thus, here too, much information is also abstracted away.

Principal Components Analysis: Clearly, given the similarities amongst these density measures, substantial multi-collinearity may exist between them, thus complicating attempts to attribute explanatory power in a regression to any or all of these variables. Indeed, Pearson and Spearman correlations amongst these variables reveal such multi-collinearity [see Table 2].
Thus, in an attempt to avoid multi-collinearity between the density variables while also allowing for more parsimonious models and improved measurement of indirectly observed concepts (Hamilton 1992), we employ principal components analysis to construct one composite density measure. The component explaining the majority of the variance in the six density variables also has positive loadings on all six measures, and thus can be interpreted as a "density" component. We create a composite density index by linearly combining the six density variables, standardized and weighted by the component loadings[11].

Finally, as a descriptive exercise, Table 3 examines examples of several MSAs measured on each of the density measures, including the composite index. Given that the composite index is a linear combination of standardized variables, positive observations indicate above average densities, while negative values indicate below average densities.

<u>Innovation:</u> The dependent variable measures innovation by using simple utility patent count data downloaded from Hall, Jaffe, and Trajtenberg's NBER patent database, but originally available from the U.S. Patent and Trademark Office. Specifically, we measure 1999 metropolitan area utility

patents per 100,000 people. Also, as described later, we use 1990 metropolitan area utility patents per 100,000 people as an independent variable. As explained by Hall, Jaffe, and Trajtenberg (2001), patents have numerous advantages as data for the study of innovation and technological change. First, patents contain highly detailed information on the innovation itself, but also about the inventor, the originating technological area(s) and industry, etc. Second, there is both a very large "stock" and "flow" of patents, so there exists a wealth of data available for research. Lastly, patent count data reaches back at least 100 years, making available long time series of data. Of course, simple patent count data also have serious limitations. First, not all inventions or innovative ideas are patented or patentable. Second, as Hall, Jaffe, and Trajtenberg (2001, 6) note, innovations "vary enormously in their technological and economic importance" and patent counts are seriously insufficient in their ability to capture this underlying heterogeneity. Instead, as Trajtenberg (1990) notes, patent counts are found to be indicative of the input side of the innovative process, as in R&D expenditures. To address these limitations, all analyses will also be conducted using citation-weighted patents as the dependent variable, since "patent counts weighted by a citations-based index appear to be highly correlated (over time) with independent measures of the social gains from innovations" (Trajtenberg 1990, 172). Another shortcoming of simple patent counts is that patents are heavily concentrated in particular industries. For example, patents work especially well in bio-technology, an industry heavily tied to universities. Thus, since our patent data reveals the industry to which the patent applies, we can also construct industry weighted patent data, and thus we will also conduct all analyses with this dependent variable.

<u>Creative Capital:</u> This is a measure invented by Florida and Stolarick[12] using data from the 1999 Bureau of Labor Statistics Occupational Employment Statistics Survey. The intent of the measure is to capture all employment in a region that has a creative component. The survey provides counts of employees in different occupational categories, so thus we can compute the percentage of creative

employees for each PMSA. Yet, since the explanatory variables must temporally precede the dependent variables in order to simulate causation, and since the Florida/Stolarick measure uses data from the same year as the innovation data, we had to re-create the creative capital variable using the 1990 Decennial 5 percent Census Public Use Microdata Sample[13].

As mentioned earlier, studies by Florida and Gates (2001), Florida (2000, 2002a, 2002b), and Lee (2001) link the presence of gays and bohemians to innovation and/or growth. They explain this by claiming that new ideas arise due to a multiplicity of people and perspectives, and that the presence of gays and bohemians in metropolitan areas is indicative of a tolerance of such a wide variety. Thus, we want to account and control for these factors in our regressions.

Gay Index: This variable, originally calculated by Black et al (2000), is based on the 1990 PUMS data, and is a location quotient measuring the over- or under-representation of coupled Gays and lesbians in an MSA. See Black et al (2000) for more information on this measure.

Bohemian Index: This variable, attributable to Florida (2000, 2002a, 2002b), is also based upon the 1990 PUMS, and is a location quotient of the number of bohemians in an MSA. As Lee (2001) notes, it includes authors, designers, musicians, composers, actors, directors, painters, sculptors, craft-artists, artist printmakers, photographers, dancers, artists, and performers.

Research and Development: MSA-level total R&D is not available, and thus must be estimated. A simple estimate is a linear combination of state-level R&D and the MSA-level percentage of scientists and engineers. We employ a very unrestrictive combination, by simply additively including the two variables in a linear regression[14]. State-level R&D is available via the National Science Foundation's Web Caspar[15]. As noted in Lee (2001), scientists and engineers serve as a proxy for R&D expenditures. Scientists and engineers as a percentage of total MSA employment is available from the 1990 Decennial Census 5 percent PUMS, and is calculated on a per capita basis.

Milken Tech-Pole Index: As DeVol et al (2001) state, "Regional clusters [of high-tech industry] may be more important in fostering innovative economic activity than the large multinational corporations that engage in promoting it." Thus potentially, the prevalence or spatial concentration of high-tech industry in a metropolitan area may be highly related to the metro's capacity for innovation. Thus, measures of this concentration are used here as proxies for patents to test the robustness of the empirical models. We make use of the measures of high-technology industry spatial concentration constructed by DeVol et al of the Milken Institute. They form their "Tech-Pole" index by multiplying together their two individual measures of concentration, (1) high-tech location quotient[16] and (2) the metro area proportion of national high-tech output. The location quotient effectively measures the importance of an industry on a local economy, but unfortunately does not adjust for the size of the city. Therefore, on this measure, the impact of small metros with high local concentrations of high-tech industry on the national economy may be exaggerated. Likewise, large metros may rank highly on the measure of metro area proportion of national high-tech output simply due to their size. To alleviate these concerns, DeVol et al formed a composite index that combines the two measures by multiplying them. The composite measure is their "tech-pole", and is intended to measure the technological "gravitational pull" that a metro exerts.

Creative – Density Interaction: To assess the joint effects of creativity and density on innovation, we construct a multiplicative interaction term of the scaled composite density index and percentage creative capital. We feel this measure provides a good proxy for the actual density of creative capital[17]. One would expect actual creative density to increase with overall density, and fortunately, we observe our interaction term increasing with overall density. This variable is of primary interest in our empirical tests, and if our theories are borne out by the data we expect this interaction term to obtain a positive coefficient. A final comment about this measure should be made. Clearly, creative capital is comprised of engineers, scientists, artists, architects, athletes, and several other occupations. Obviously, this measure is present in all regressions, but, importantly, also included separately are bohemians and percent scientists and engineers. Seemingly, one could raise the objection that we double-count scientists and engineers and bohemians, given that they are controls in the regressions and are part of the creativity measure. However, we feel that creative capital should be conceived as an entity unto itself, and that important "reactions" or "interplay" occur when its individual components are interspersed together that differ from those occurring if only scientists and engineers or only bohemians were present. So, the whole is greater than the sum of its parts. We still need to account in a regression for the individual effects of scientists and engineers and bohemians, to reinforce the predominant importance of the "reactions" described above.

IV. Findings

Regression Estimation Results:

We estimated a series of regressions and other tests to assess the evidence for our theories[18]. Table 4 provides OLS estimation results using 1999 patents per 100,000 people as the dependent variable. The results provide ample evidence in support of our theory. The coefficient on the creativity-density interaction term from this regression is positive (2792.2) and significant, as expected. This result lends weight to our hypothesis that the density of creative workers facilitates innovation. Furthermore, we might be interested in the marginal effects of the Composite Density Index and 1990 Percent Super-Creative Employment on 1999 patents per 100,000 people. To recover these marginal effects, we compute the respective coefficients with all other variables at their means. When this is done, we observe that the Composite Density Index coefficient is now positive (30.96), and the Creative Capital coefficient is also positive (222.9). These results both align with our theories.

A very interesting, unexpected, and counter-intuitive result is that the percentage of scientists and engineers appears to have a negative impact on 1999 patents per 100,000. This result is most likely driven by places with high patenting and low scientists and engineers, and vice versa. In truth, one might actually expect a low correlation between patenting and scientists and engineers. A region with a large percentage of its workforce in science and engineering jobs will not necessarily be more innovative. Patents are a reflection of "unorganized" innovative efforts that are not company driven, as well as a reflection of company driven ones. We might also conjecture that the negative correlation is actually a reflection of scientific or research bureaucracy. More scientists and engineers might entail more overhead and not necessarily better innovative results. Metro areas like Boise, Idaho, Santa Cruz, California, Rochester, New York, and Rochester, Minnesota produce more patents with less scientists and engineers, while The District of Columbia, Los Angeles, New York City, and Chicago, Illinois patent less with more scientists and engineers. San Jose, California is the only exception. San Jose might be the exception because of its preponderance of small firms rather than bigger ones. That is not to say large firms are bad. A predominate large firm can achieve wonderful innovative results. However, in general, it is possible that higher per capita scientists and engineers are more associated with increased bureaucracy and lower innovative results. Additionally, scientists and engineers might be more positively correlated with measures of technological output, than measures of innovation like patents. Indeed, in additional tests described below, we observe a statistically significant positive relationship between scientists and engineers and the 2000 Milken Tech-Pole Index. Finally, since scientists are included in the creativity measure, we should look at their effect on innovation without creativity and creative-density in the regression. When we remove these two variables, scientists and engineers has a positive but insignificant effect on 1999 patents per 100,000. Without creativity and creative-density, scientists and engineers still positively and significantly effect 2000 Milken Tech-Pole, the Milken high-tech location quotient, and the Milken tech-share.

Also notable from Table 4 is the insignificance of both the bohemian and gay indices. Apparently, relative to the effects of creative-density, these variables, along with percent scientists and engineers, play a lesser role in facilitating innovation. The noticeable positive effects of the creative-density term on innovation as compared to the negligible effects of bohemians and scientists and engineers taken alone points to the importance of conceiving of a more inclusive creative class, as Florida (2002c) does. Important for the current analysis though, it especially points to the importance of the interactions between the members of this broader "class". As postulated earlier, the "whole" of this class is greater than the sum of its parts, in large part due to the relationships between its members that are made possible by density[19].

Finally, we note the very small, insignificant coefficient on 1990 State total R&D per 100,000 people. First, given that this variable is measured at the state level instead of at the PMSA level, potentially it does not achieve as much variation as our other variables, thus effecting its' usefulness in hypothesis testing. Theoretically though, the slightly negative coefficient could indicate that there are decreasing returns to R&D dollars, which is a fairly standard conclusion in contemporary R&D research.

<u>Regressions Estimations by metro size:</u> Although all of the variables included in regressions to this point have been in per-capita terms, we have not sufficiently dealt with the possibility that creative-density might have a different effect on innovation among cities of different sizes. In other words, we need to consider the possibility that size and density might interact. For example, we might think

that even after variables are in per-capita terms, bigger cities have inherent qualities or advantages that increase the effect of creative-density on innovation. Of course, there is also the issue that bigger cities are typically denser, which is demonstrated by the correlation of 0.53 between the composite density measure and 2000 population. To account for this potential interaction, we first estimated four separate regressions for various metro size quartiles (1 million and above, 500,000-1million, 250,000-500,000, and less than 250,000). The overriding result suggests that, in fact, the effect of creative-density on innovation is in absolute terms largest for the largest metros (above 1 million population), and the relationship is only significant at that size level. This result does not imply that creative-density does not matter and that metro size is the only meaningful explanatory factor, but that creative-density and size positively interact. Of course, these quartiles are somewhat arbitrary, and so another option is to estimate one regression with a creative-density*population interaction term. When we estimate this regression (see Table 5) with 1999 patents per 100,000, the coefficient on creative-density is again positive and significant, and in fact has a larger coefficient than in Table 4 (4344.5 to 2792.2). Interestingly, the effect of the interaction between creative-density and population on patents is close to zero and significant. Seemingly then, these city size results are mixed and inconclusive. However, if we decide that density were to primarily play a positive role among larger cities, a policy recommendation arising from this would be that larger cities with high creative-densities should undertake measures to maintain them or risk losing their inherent innovative advantage[20].

Causality Issues: Briefly, we will discuss our methods for dealing with potential reverse causality or endogeneity questions in our models. To mitigate the possibility that causality might run in the opposite direction, we ensure the appropriate temporal nature of our variables, making sure all of the independent variables precede the dependent variables. Second, we control for the initial stock of innovation, thus separating the role of creativity and density from their capacity for just proxying for innovation.

More specifically, one might argue that innovation raises incomes, thus subsequently raising people's abilities and desires to fund museums and other artistic undertakings. We recognize this as a potential issue, and could look for instruments for our creativity measures. One such measure might be per-capita spending on the arts, however this might only capture "mainstream" cultural programming and not the more "bohemian" culture we are attempting to capture. Actually though, this argument would support the finding that there is a high correlation between innovation and bohemians rather than creatives. Yet, the creative measure is not a proxy for bohemians. The creative measure primarily captures artists, computer scientists, science, architecture, and education workers. Importantly, we find that bohemians do not significantly enter regressions when they are included alongside creatives, evidence against the above "art-funding" argument.

Future Research: While outside the scope of this research project, several interesting possibilities remain for future research. As mentioned above, we would like to evaluate the effect of the absolute number of creative workers on innovation and also create an actual "creative density" measure. However, potentially more pressing is the fact that our density measures neglect differences in density within metro areas, instead averaging over these differences. To deal with this, we could create a weighted average density measure, weighting by the population of each census tract, and then aggregating up to the MSA[21]. Clearly then, dense, highly populated tracts would be weighted heavily.

Also, as the data becomes available, it would be preferable to consider analyses done in this study at a unit smaller than the MSA/PMSA. For the purposes of deciphering how population density relates to and influences idea flows and knowledge generation, the Metropolitan Area is likely too large a unit of observation. This is especially true if the majority of "new knowledge" flows from particular clusters in the MSA or PMSA, like a central city or county. Given this, if we were to use a smaller unit of observation, when we computed the measure "patents-per-capita" we would no longer divide the number of patents by the total MSA population like we do now, but only by the "clusters'" population. Thus, not only would we observe higher patents-per-capita, but likely also a greater association between new knowledge and density. However, this caveat aside, for a first take, observing these relationships at the MSA/PMSA level is still a useful exercise.

V. Conclusions

Society values innovation due to its links to economic growth and increased standards of living, and thus hopes to identify and promote those factors that facilitate it. Public policies can be the mechanisms through which society enables that promotion to occur. To the extent that this study is successful at demonstrating the link between creative-density and innovation, seemingly then metropolitan areas should adopt policies aimed at "densifying". Yet, in our estimation, this policy approach does not easily follow from the current study, for the following reasons. To the extent that we succeed at linking creative-density with a desired outcome like innovation, we shed light on the question of "what conditions the demand for density?" or in other words, "why do creative people value density and locate in dense places?" It helps to answer these questions under the assumption that creative people can anticipate these desired associations, and are induced to locate in a region to take advantage of them. However, these kinds of studies treat density as a fixed variable that regions already possess (or don't possess), and thus the observed relationships between density and the desired outcome only serve to induce the marginal person to the region, while providing little insight into how to generate a critical mass of density when none previously existed. This latter issue is perhaps better characterized by the question "why and how do people organize themselves into cities or dense places in the first place" and is possibly best answered by researching historical case studies or by pursuing further quantitative analyses. Thus, while specific policies of how to promote creative-density for specific places do not directly flow from the study at hand and will be better determined by future research, by documenting the links between creative-density and innovation the current study reveals the importance of looking for answers to this latter question.

Of course, for cities that already possess a critical mass of creative-density and are able to attract the "marginal" person, then they can and should adopt policies that sustain their existing creative-density. This is extremely important in light of findings by Fulton et al [16] that regions that are already dense have a harder time retaining their density, since they tend to urbanize more land than necessary to accommodate population growth. This is a public policy failure, and with attention, could be rectified.

Finally, until now we have implied only that creative-density induces people to locate in regions due to its productivity effects. Yet, creative-density's impact on the scale and form of social interactions and structures might also induce people to locate in regions. As posited extensively by Florida (2002c), this social structure plays a key role in innovation and regional growth, and thus policy-makers need to be cognizant of its effects and open to promoting and fostering it. Glaeser (2000, 108) alludes to creative-density's effects on social structures when he writes: "[a]nother benefit of urban density is the supply of social interactions outside the workplace….Indeed, the demand for New York (or Paris, for that matter) comes in part from the remarkable social life that is possible in that city. That social life is a function, in no small part, of the population density within the city." Glaeser (2000, 138) continues by adding that:

> Gary Becker has argued that restaurants attract customers because of their crowds as much as because of their food. It seems to be appealing to many people to live close to (if not directly on) bustling city streets. Young single people in particular flock to cities because urban density makes for thicker matching in the marriage market.

> Finding an appropriate mate is generally thought to be much harder in rural Iowa than in Manhattan.

Consequently, we hope that arising from this study will be a fuller understanding of the spatial determinants of innovation, and recognition that creative-density potentially conditions location choice both through productivity effects and through impacts on social structures. While left unexplained by this study, investigating the impacts of creative-density on social structures is a fruitful area for future research.

Notes:

[1.] In this study, given the data available, we do not test the explicit relationships between constructs as posited in the theory section, but instead conduct tests that are reflective of these relationships. If the tests display relationships between the variables that are broadly commensurate (in terms of directionality) with the theory, then the mechanisms described in the theory can be considered an explanation for what we observe. Of course, the tests arise from the theory, not the other way around.

[2.] Reference to Boyle's Gas Laws makes this point more clear. Boyle's Law states that given constant temperature, gas pressure and volume are inversely proportional. In simple terms, if you were to increase the volume of a container holding a gas, the pressure would decrease. This would result because the increased distance between gas particles results in fewer numbers of collisions between them. If we roughly conceive of individuals as "particles", the less densely concentrated people are, the greater the distance between them, and the fewer the collisions or interactions. Of course, Boyle's law also provides interesting intuition into what would happen to a region that "expanded its volume" without increasing its number of "particles". Such an occurrence might result in a place becoming less dense, and, having fewer interactions than it did previously. Refer to dbhs.wvusd.k12.ca.us/webdocs/GasLaw/Gas-Boyle.html for more information.

[3.] One might ask the question, "Where do the face-to-face interactions between individuals occur, at home, at work, or in between?" To the extent that, in the main, people are assumed to live and work in the same MSA/PMSA, this question does not apply, and will not affect these analyses. If we were to employ a finer unit of analysis, then we would have to more deftly address this question, and would likely need to consider what kind of density measure (residential, industrial, some mix of the two) would most closely capture the interactions.

[4.] We do not restrict our definition of density to employment density, as do Carlino, Chaterjee, and Hunt (2001, 2005), because we do not want to restrict the interactions to ones occurring at work or in employment environments. Urban, dense places make possible many kinds of interactions, in different places, and amongst and between many kinds of people. We posit that these diverse interactions promote innovations. We thus feel that there is benefit to keeping the definition of density broad.

[5.] The most recent MSA definitions are for 1999, thus explaining the 1999 land area. The Office of Management and Budget will make available 2000 MSA definitions later in 2002.

[6.] www.census.gov/population/cen2000/phc-t3/tab01.txt – this file has population data for Metropolitan Areas and their components for 1990 and 2000, using 1999 MSA definitions.

[7.] factfinder.census.gov

[8.] A number of important points need to be made clear about land area. First, it is assumed that the component land area (county, town, etc) does not change much over time. Thus county or town land area data from the 2000 Census Factfinder is taken to pertain equally well to 1990. Changing much however are the MSA and PMSA definitions across years, in this case 1990 to 1999. These changes are primarily reflected in differences in the components that comprise the MSAs. Counties are often added and dropped from MSAs, and we have accounted for these changes in our calculations of MSA/PMSA land areas for these two years. In making these changes, two issues arose. First, in 1990, some regions were defined as an MSA, but in 1999 were subsumed under an existing MSA/CMSA. When this happened, we conclude that the MSA/CMSA existed in 1990 (without the subsumed MSA), and thus have them both included as datapoints in 1990. Second, in several cases, regions existed as CMSAs in 1990, but then became MSAs in 1999. Given that no new counties are added or dropped, I simply use the MSA definition for both 1990 and 2000.

[9.] As documented in the Fulton et al (2001) report, urban land is defined by the NRI as follows: A land cover/use category consisting of residential, industrial, commercial, and institutional land; construction sites; public administrative sites; railroad yards; cemeteries; airports; golf courses; sanitary landfills; sewage treatment plants; water control structures and spillways; other land used for such purposes; small parks (less than 10 acres) within urban and built-up areas; and highways, railroads, and other transportation facilities if they are surrounded by urban areas. Also included are tracts of less than 10 acres that do not meet the above definition but are completely surrounded by Urban and built-up land. Two size categories are recognized in the NRI: areas of 0.25 acre to 10 acres, and areas of at least 10 acres. The authors 1982 population data comes directly from Census estimates, and their 1997 estimates are based upon a straight line interpolation of the 1990 and 2000 Census estimates. The authors also make use of NECMA definitions for several New England regions including Boston MA, New London CT, Hartford CT, Springfield MA, Lewiston-Auburn ME, Pittsfield MA, Portland ME, Providence RI, and Bangor ME. Given that I use MSA/PMSA definitions in my dataset, I am forced to use their NECMA estimates of density in my dataset. More detailed information about their methodology is available in their report.

10. Comparing a metro's urban density across years gives an idea for the relative rates at which they are adding population and urban lands. If a metro is urbanizing land faster than it is adding population, then its urban density will decrease across years. Conversely, if a metro adds population faster than urbanized land, then urban density will increase across years. Also, a metro's marginal density will always be positive if it adds population, even when density decreases across years. But, often when land is urbanized faster than population grows, marginal density will be small. High marginal densities however are often correlated with the size of the city, so that places that have already large population bases and that add more population may tend to have larger marginal densities. So, for an individual metro more information is revealed by comparing the urban density measures across years. Finally, marginal density will be negative if a metro loses population.

11. This composite density measure is roughly in terms of standard deviations, with some values greater than zero, other less than zero. Subsequently, we interact this variable with another continuous variable, percentage creative employees in a PMSA. To ensure that each variable is on a similar scale (between 0 and 1), we re-scale the composite density index such that all values are between 0 and 1, thus creating a variable that is similar in form to percentage creative employees. The rescaled density measure takes the form:

$$\frac{CompositeDensity + (-\min CompositeDensity)}{(\max CompositeDensity) + (-\min CompositeDensity)}$$

12. The measure was introduced in The Rise of the Creative Class, Florida (2002).

13. This measure includes the following occupations: Education Administrators, Engineers, Architects, Mathematical and Computer Scientists, Natural Scientists, Postsecondary Teachers, Teachers except postsecondary, Librarians, Archivists, Curators, Social Scientists, Urban Planners, Writers, Artists, Entertainers, and Athletes.

14. One could easily conceive of more restrictive combinations. We could set up an equality of $\frac{SCI\ \&\ ENG_{MSA}}{SCI\ \&\ ENG_{State}} = c\frac{R\ \&\ D_{MSA}}{R\ \&\ D_{State}}$. Then, MSA-level R&D could be solved for.

15. caspar.nsf.gov

16. Dividing the high-tech percentage of metro output by the high-tech percentage of national output forms a location quotient (LQ) for a metro. A LQ of 1.0 means a metro's concentration of high-tech output is equal to the nation's concentration, while greater than 1.0 means a metro's concentration is higher than the nation's concentration.

17. Given our use of 1990 PUMS data, we are not able to recover the actual density of creative capital. Doing this would require that we obtain, for the numerator of a density measure, an absolute number of creative workers. But, since the PUMS primary geographic unit, the PUMA, often spills across numerous PMSAs, we are forced to exclude those PUMAs from a final total. Thus, we only use PUMAs that are entirely within a PMSA, clearly complicating any attempt to recover an absolute number of creative workers. The percentage of metro area employment that is creative is more appropriate because we assume that on average, the excluded PUMAs are not different than those included, and thus the percentage creative capital is approximately accurate. Finally, we can attempt to estimate the actual "creative-density", by multiplying the percent super-creative employment by 1990 population, and then dividing by 1990 Census land area. We did this, and note that it's correlation with the creative-density interaction is r = 0.8707. We thus use the interaction term, because it enables use of our constructed composite density index.

18. Beyond the results reported in Table 4, we estimated several other regressions using proxies for patents as the dependent variable to test the consistency of the findings. When the 2000 Milken Tech-pole Index and its components – the high-tech location quotient and tech-share – are inserted as dependent variables, the regression estimation results are very similar to those using patents as the dependent variables. The creative-density interaction is positive and significant in the tech-pole and tech-share regressions, and positive and insignificant in the location

quotient regression. Next, we estimated regressions using citation-weighted and industry-weighted patents. The interaction term once again is positive and significant. Overall, these results provide additional evidence in support of the hypotheses. Also, we undertook several procedures to guard against the possibility that our results were determined or overly reliant on the presence of outliers and influential points. First, we took out the top 5 percent of the observations from 1999 Patents / 100,000 and the creativity-density interaction term. This resulted in 22 observations being removed from the dataset. When the trimmed 1999 Patents / 100,000 is regressed on the trimmed interaction term and the other independent variables, we again observe a positive and significant coefficient on the creativity-density interaction term. Finally, the estimation results of an iteratively weighted least squares robust regression procedure also return a positive and significant coefficient on the interaction term.

[19.] When we remove creativity and creative-density, the effect of bohemians on patents turns from negative to positive, but remains unsignificant. The effect of gays on patents had been positive but insignificant with creativity and creative-density, and when we remove these two variables gays becomes significant.

[20.] An additional issue associated with metro size is that a critical mass or threshold of creative persons must be achieved before their presence can have any discernable effect on innovation. In other words, we would look to see whether the absolute number of super-creative employees matters more than the percentage, and also to see whether this critical mass predominates the effect of density. We felt that while this was an important issue, it was outside the scope of this study, and thus chose to pursue it at a later date.

[21.] However, by not using the weighted average density measure, and by using the PMSA as our unit, we are able to construct and use the composite density index. The value of this composite index was discussed earlier.

References

Audretsch, D., and Feldman, M. 1996. R&D Spillovers and the Geography of Innovation and Production. The *American Economic Review* 86:630-640.

Autant-Berard, C., and Massard, N. 2001. Scientific interactions, geographic spillovers and innovation: An empirical study on the French case. Working paper, CREUSET, University Jean Monnet Saint Ettienne.

Black, D.; Gates, G.; Sanders, S.; and Taylor, L. 2000. Demographics of the Gay and Lesbian Population in the United States: Evidence from Available Systematic Data Sources. *Demography* 37:139-154.

Carlino, G.; Chaterjee, S.; and Hunt, R. 2001. Knowledge Spillovers and the New Economy of Cities. Working Paper No. 01-14, Federal Reserve Bank of Philadelphia.

------. 2005. Matching and Learning in Cities: Urban Density and the Rate of Invention. Working Paper No. 04-16/R, Federal Reserve Bank of Philadelphia.

Ciccone, A., and Hall, R. 1996. Productivity and the Density of Economic Activity. *The American Economic Review* 86:54-70.

Cohen, W., and Levinthal, D. 1994. Fortune Favors the Prepared Firm. *Management Science* 40:227-251.

Desrochers, P. 2001. Local Diversity, Human Creativity, and Technological Innovation. *Growth and Change* 32:369-394.

DeVol, R.; Wong, P.; Catapano, J.; and Robitshek, G. 2001. America's High-Tech Economy; Growth, Development, and Risks for Metropolitan Areas. Milken Institute.

El Nasser, H., and Overberg, P. 2001. "A Comprehensive Look at Sprawl in America." *USA Today*, 22 February.

Feldman, M. 2000. Location and Innovation: The New Economic Geography of Innovation, Spillovers, and Agglomeration. In *The Oxford Handbook of Economic Geography,* eds. G. Clark, M. Gertler, and M. Feldman, 373-394. Oxford,UK: Oxford University Press.

Florida, R. 2000. Competing in the Age of Talent: Quality of Place and the New Economy. Report to the Richard King Mellon Foundation, Pittsburgh Pa.

------. 2002a. The Economic Geography of Talent. *Annals of the Association of American Geographers* 92:743-755.

------. 2002b. Bohemia and Economic Geography. The *Journal of Economic Geography* 2:55-71.

------. 2002c. *The Rise of the Creative Class*. New York, NY: Basic Books.

Florida, R., and Gates, G. 2001. Technology and Tolerance: The Importance of Diversity to High-Technology Growth. Brookings Institute, Center for Urban and Metropolitan Policy.

Fulton, W.; Pendall, R.; Nguyen, M.; and Harrison, A. 2001. Who Sprawls Most? How Growth Patterns Differ Across the U.S. The Brookings Institution, Center on Urban and Metropolitan Policy.

Glaeser, E. The Future of Urban Research: Nonmarket Interactions. *Brookings-Wharton Papers on Urban Affairs* 2000, 101-150.

Griliches, Z. 1979. Issues in Assessing the Contribution of Research and Development to Productivity Growth. *The Bell Journal of Economics* 10:92-116.

------. 1992. The Search for R&D Spillovers. *Scandinavian Journal of Economics* 94 supplement 29-47.

Hall, B.; Jaffe, A.; and Trajtenberg, M. 2001. NBER Working Paper 8498, The NBER Patent Citations Data File: Lessons, Insights, and Methodological Tools.

Hamilton, L. 1992. *Regression with Graphics: A Second Course in Applied Statistics*. Belmont, CA: Duxbury Press.

Howells, J. 2000. Knowledge, Innovation, and Location. In *Knowledge, Space, Economy,* eds. J. R. Bryson, P. W. Daniels, N. Henry, and J. Pollard, 50-62. London, UK: Routledge.

Jacobs, J. 1970. *The Economy of Cities*. New York, NY: Random House.

Jaffe, A. 1986. Technological Opportunity and Spillovers of R&D. *American Economic Review* 76:984-1001.

Lee, S. 2001. Innovation, Human Capital, and Diversity. Working Paper, H. John Heinz III School of Public Policy and Management, Carnegie Mellon University.

Lucas, R. 1988. On the Mechanics of Economic Development. *Journal of Monetary Economics* 22:3-42.

Romer, P. 1990. Endogenous Technological Change. *Journal of Political Economy* 98:S71-S102.

Sedgely, N., and Elmslie, B. 2004. The Geographic Concentration of Knowledge: Scale, Agglomeration, and Congestion in Innovation across U.S. States. *International Regional Science Review* 27, 2:111-137.

Storper, M., and Venables, A. (2004). Buzz: face-to-face contact and the urban economy. *Journal of Economic Geography* 4:351-370.

Strumsky, D.; Lobo, J.; and Fleming, L. 2005. Metropolitan Patenting, Inventor Agglomeration and Social Networks: A Tale of Two Effects. Los Alamos National Laboratory Technical Report LAUR-04-8798.

Trajtenberg, M. 1990. A Penny for Your Quotes: Patent Citations and the Value of Innovations. *The Rand Journal of Economics* 21:172-187.

Zucker, L.; Darby, M.; and Brewer,M. 1998. Intellectual human capital and the birth of U.S. biotechnology enterprises. *American Economic Review* 88:290-306.

Table 1: Descriptive Statistics

Variable	Obs	Mean	Std. Dev	Min	Max
1990 Census Population Density	321	430.12	855.04	11.47	11768.06
2000 Census Population Density	331	438.08	921.36	5.41	12956.90
1982 Urban Density	325	2998.35	1764.19	647.32	22311.08
1997 Urban Density	327	2354.68	1261.82	775.32	12604.75
Percent in Urbanized Areas	326	69.45%	16.13%	22.50%	98.30%
Marginal Density	325	997.86	1386.55	-4133.41	9318.94
Composite Density	294	0.00	1.85	-2.09	18.62

1990 Super Creative percent	273	8.91%	2.60%	4.35%	19.58%
1999 Patents / 100,000 pop.	331	25.39	31.89	0	281.06
1990 Patents / 100,000 pop.	313	17.47	16.95	0	111.10
1990 Bohemian Index	242	0.924	0.366	0.316	2.90
1990 Scientists & Engineers	273	0.719%	1.28%	0.02%	9.32%
1990 Gay Index	331	0.659	0.695	0.00	8.75
1990 State R&D / 100,000 pop.	50	6334.29	2770.53	1950.11	20270.26
2000 Milken Tech-Pole	315	0.507	2.01	.000025	29.96
2000 Milken Location Quotient	346	0.827	0.726	0.032	5.167
2000 Milken Tech-Share	346	9.23	28.53	0.0008	100
1990 Citation Weighted Patents / 100,000 pop.	309	121.83	144.59	0.764	890.10
1999 Citation Weighted Patents / 100,000 pop.	329	1.043	2.06	0.00	19.08
1999 Industry Weighted Patents / 100,000 pop.	329	22.24	21.70	0.151	156.61

Table 2: Density Correlation Matrices

<u>Pearson Correlations</u>

	(1)	(2)	(3)	(4)	(5)	(6)
(1) Census Density 1990	1					
(2) Census Density 2000	0.9948	1				
(3) Percent in UA	0.3068	0.3001	1			
(4) Urban Density 1982	0.5375	0.5298	0.2556	1		
(5) Urban Density 1997	0.7557	0.751	0.3751	0.7298	1	
(6) Marginal Density	0.0447	0.0622	0.3008	0.1959	0.4565	1

Spearman Correlations

	(1)	(2)	(3)	(4)	(5)	(6)
(1) Census Density 1990	1					
(2) Census Density 2000	0.9645	1				
(3) Percent in UA	0.4405	0.4403	1			
(4) Urban Density 1982	0.3504	0.3159	0.3023	1		
(5) Urban Density 1997	0.3943	0.3867	0.4285	0.8712	1	
(6) Marginal Density	0.1523	0.194	0.3173	0.1005	0.3606	1

Table 3: Density Measures

Region	Census Population Density*	Urban Density#	Marginal density	Percent in UA	Composite Index
>1,000,000 persons					
Washington, DC	989.55 756.24	3990.9 3208.2	1890.9	78%	1.26
Pittsburgh, PA	584.7 510.0	3441.3 2239.4	-581.9	71%	-0.01
Boston, MA	1632.8 1694.5	4161.6 2956.6	646.1	77%	1.86
New York City	7490.7 8163.2	13560.2 12438.6	4090.8	92%	14.84
>500,000 & <1,000,000 persons					
Akron, OH	726.6 767.9	2970.3 2135.6	308.78	83%	0.37
Jersey City, NJ	11768.1 12956.9	13611.6 12604.8	-4133.4	92%	18.62
Little Rock, AR	176.5 200.8	2087.5 1719.7	784.8	54%	-1.01
Tulsa, OK	141.4 160.2	2103.6 1764.6	650.3	66%	-0.84
>250,000 & <500,000 persons					
Columbus, GA	219.8 174.9	3137.9 1889.5	232.3	83%	-0.28
Corpus Christi, TX	228.9 249.2	2417.1 1923.4	722.7	76%	-0.45
Lancaster, PA	445.5 496.0	2354.6 1973.6	1144.4	45%	-0.66
Trenton, NJ	1441.7 1552.0	3499.3 2699.3	616.1	92%	1.66
<250,000 persons					
Abilene, TX	130.6 138.2	3124.3 2301.9	111.9	90%	-0.09
Bellingham, WA	60.3 78.7	2121.7 2044.2	1874.9	44%	-1.02
Duluth-Superior, MN-WI	31.9 32.4	2097.3 1454.9	-639.6	51%	-1.51
Rapid City, SD	29.3 31.9	1494.4 1134.5	521.4	75%	-1.22

* Top value refers to 1990, the bottom value refers to 2000
# Top value refers to 1982, the bottom value refers to 1997

Table 4: OLS Regression with Patents

Dependent Variable: **1999 Patents / 100,000 population**	(1)	(2)	(3)	(4)	(5)
Independent Variables:					
Composite Density Index*	-306.89 (0.000)	-218.10 (0.000)	2.32 (0.899)	-323.80 (0.000)	-3.47 (0.850)
1990 % Super-Creative Employment*	152.72 (0.183)	-59.20 (.534)	180.99 (0.012)	66.03 (0.593)	
Creativity-Density Interaction Term	4032.35 (0.000)	2792.2 (0.000)		4082.7 (0.000)	
1990 Bohemian Index		-0.100 (0.986)	-1.16 (0.847)	12.60 (0.096)	4.65 (0.409)
1990 Percent Scientist & Engineers		-162.41 (0.252)	33.33 (0.805)	-97.51 (0.598)	42.44 (0.756)
1990 Gay Index		4.00 (0.116)	5.19 (0.046)	1.63 (0.622)	5.49 (0.037)
1990 State R&D / 100,000 population		-0.00025 (.701)	-0.00005 (0.939)	-.00077 (0.359)	0.00019 (0.764)
1990 Patents / 100,000 population		1.27 (0.000)	1.32 (0.000)		1.39 (0.000)
Constant	6.41 (0.520)	5.616 (.520)	-15.53 (0.024)	8.26 (0.468)	-7.09 (0.238)
Adjusted R-Squared	0.2614	0.5694	0.5454	0.2669	0.535
N	240	240	240	240	240

p-value in parentheses

* To recover the marginal effects of both the Composite Density Index and 1990 Percent Super-Creative Employment, we compute the respective coefficients with all other variables at their means (from column (2)). When this is done, we observe:

i) (1999 Patents / 100,000 population) = 22.3 + 30.96 (Composite Density Index)
ii) (1999 Patents / 100,000 population) = 5.6 + 222.9 (1990 Percent Super Creative Employment)

Clearly, the coefficients on Density and Creativity are both positive, as theory would predict.

Table 5: OLS Regression with Patents, controlling for population

Dependent Variable: **1999 Patents / 100,000 population**	(1)	(2)
Independent Variables:		
Composite Density Index*	-440.08 (0.000)	-296.51 (0.000)
1990 % Super-Creative Employment*	-87.37 (0.475)	-216.23 (0.037)
Creativity - Density Interaction Term	6636.42 (0.000)	4344.53 (0.000)
(Creativity – Density) * 1990 population	-0.0002 (0.000)	-0.0002 (0.001)
1990 Bohemian Index		5.38 (0.366)
1990 Percent Scientist & Engineers		1.19 (0.993)
1990 Gay Index		1.63 (0.527)
1990 State R&D / 100,000 population		-0.0004 (0.534)
1990 Patents / 100,000 population		1.18 (0.000)
Constant	19.81 (0.049)	12.81 (0.145)
Adjusted R-Squared	0.3177	0.5892
N	240	240

p-value in parentheses