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ADVANCED TECHNOLOGY PROGRAM

Placing Innovation:
A Geographic Information Systems (GIS) Approach to Identifying Emergent Technological Activity

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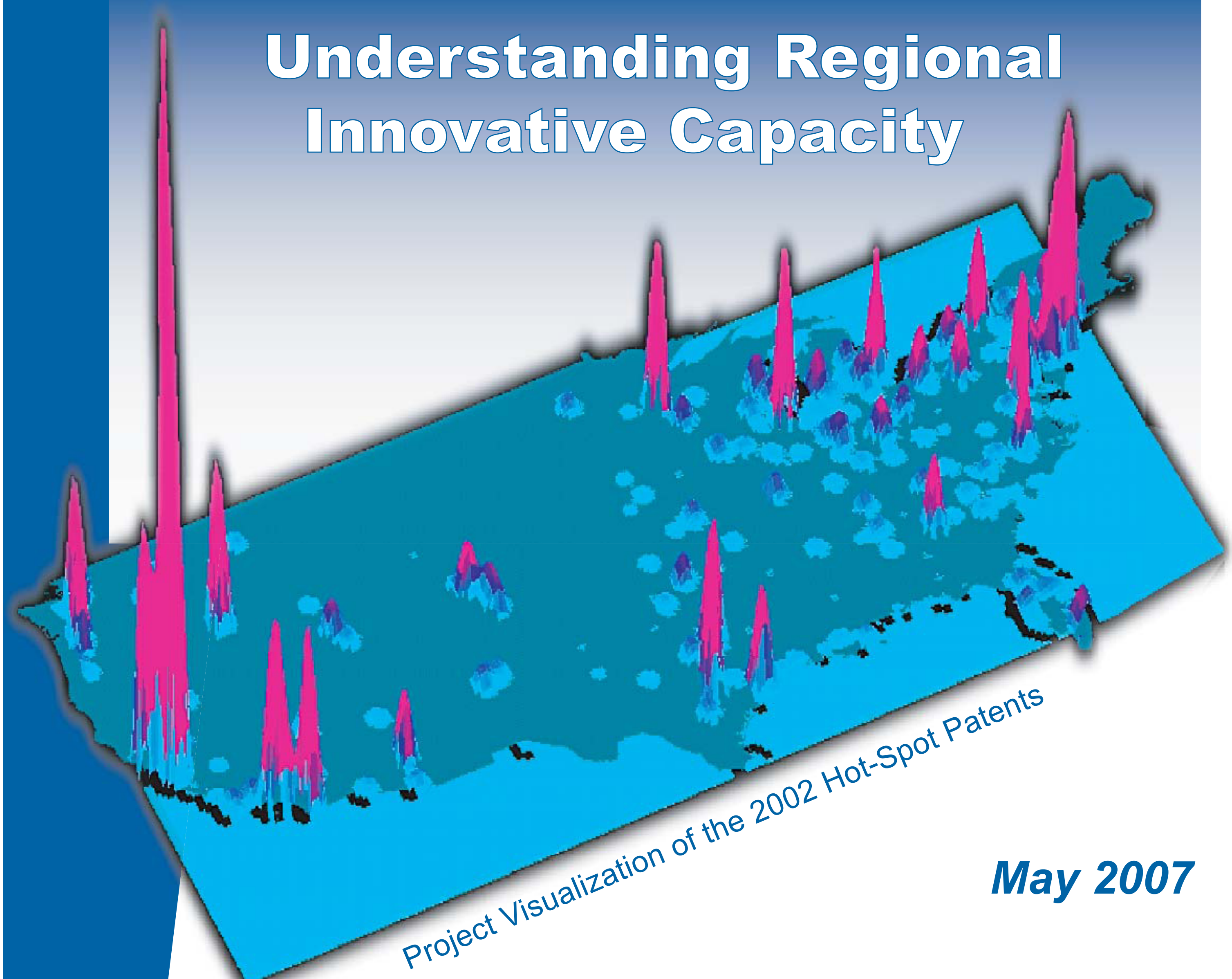
Understanding Regional Innovative Capacity



Project Visualization of the 2002 Hot-Spot Patents

May 2007

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Placing Innovation:
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Final Report of the Project on Understanding Regional Innovative Capacity

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Kathleen McTigue, EAO Economist, reviewed the paper, responded to other reviewers comments, and provided substantive editing and stylistic imput. She also oversaw publication of the report. There were also several reviewers of the paper. Prasad Gupte, an economist in ATP's Economic Assessment Office, and Stephanie Shipp, Director, EAO, read several drafts and provided comments. Barbara Cuthill, ATP Information Technology Group Leader; Lorel Wisniewski, ATP's Deputy Director; and Brian Belanger, former ATP Deputy Director and now a consultant, read final versions of the paper.

Work was performed by Mediacom Inc., a Washington, D.C. corporation, under DOC/NIST contract # SB 1341-03-W-1235. Research team members are listed in alphabetical order on the title page. Auerswald is the President of Mediacom Inc. and was the principal investigator for the project. Branscomb, Gorman, Kulkarni, and Schintler contributed as consultants. The listing of research team members' affiliations does not imply funding support from the institutions listed. Mediacom Inc. bears the full responsibility for the contents of the report. For helpful comments we thank NIST reviewers and seminar participants at the Wilson Center and at Rutgers University (Department of Agriculture, Food, and Resource Economics). We appreciate the assistance with research and data analysis provided by Jerald Coughter and Paul Fowler. We thank the National Business Incubation Association for sharing with us data on the location of business incubators in the United States.

Executive Summary

The objective of the project "On Understanding Regional Innovative Capacity," conducted in 2004 and 2005, was to inform the design of public policies to support local economic development and to foster innovation within communities. Jointly applying new techniques in mapping and visualization with existing insights from the study of innovation systems, the project addressed one core question: How can policymakers identify regional communities that have an emergent capacity for technological innovation? This paper sets forth an exploratory methodology in an attempt to answer this question. The question is difficult to answer for at least three reasons:

- First, measuring technological innovation is difficult. Patents are most often used as an innovation indicator. Patents measure invention (a novel technical idea with market potential), however, and not innovation (the successful application of that idea in markets). Furthermore, significant differences in the propensity to patent exist among different industries, and may also exist between process and product patents. Many innovations are not patented at all. Alternatives to patenting include intellectual property protection through copyright law or trade secret law, or development through an open source model.

- Second, hypotheses regarding the drivers of regional innovation are numerous and diverse, making it a challenge to rigorously test their individual impact. Statistical techniques exist that are capable of ordering the relative magnitude of correlations in complex, dynamic systems. Such techniques are complex and nontransparent, however, and consequently are potentially viewed with skepticism in a policy context by readers who are not technically trained.

- Third, the identification of the drivers of technological innovation is subject to what econometricians refer to as an endogeneity problem—the statistical version of the chicken-and-the-egg problem. Most drivers of regional innovative capacity are also affected by regional innovative capacity. For example, venture capital firms may drive a region's capacity for technological innovation, but they are also more likely to set up shop in, or relocate to, regions that already have a well-developed capacity for regional innovation. Differentiating simple correlation (two phenomena are observed to occur at the same time) from causation (phenomenon number 1 causes phenomenon number 2) is also difficult.

This report examines two of the three challenges involved in identifying communities with emergent capacity for technological innovation: (1) we describe a new approach to measuring innovation, and (2) we assess in a straightforward manner the relative importance of diverse hypotheses regarding innovation correlates. This report does not examine the third and most difficult challenge: going beyond the identification of correlations to establish causality. The challenge of establishing causality is left to future research.

Building on other work funded by the Economic Assessment Office (EAO) of the Advanced Technology Program (ATP) and performed by CHI Research, we employ a novel approach using patents as an innovation measure that takes advantage of information in patent citations to identify emergent technological clusters of innovation. (The method does not address the fact that some types of innovations are more likely to be patented than others.) A transparent method of organizing the data is used to identify the relative correlation of diverse factors with the capacity for technological innovation. The variables employed are selected to represent one of four specific hypothesized drivers of regional innovation: infrastructure, creativity, culture, and social capital. Throughout the report, geographic information system (GIS) mapping tools are used to represent the data gathered in an intuitively accessible manner.

With the preceding caveats about the data in mind, the key findings of the report are as follows:

- Although innovative activity is dominated by a few regions, rapid rates of growth in innovative activity are evidenced by a broad distribution of cities throughout the country.

- The extent of the concentration of innovative processes is at least as great within states (and Metropolitan Statistical Areas, or MSAs) as it is between states (and MSAs).

- The regions in which innovative activity evidences rapid rates of growth are likely to be either small college towns or urban peripheries.

- The spatial trajectories of particular technologies are highly varied. In most cases, technologies appear to diffuse outward from a few source points rather than to concentrate.

- Although other authors have found that the concentration of creative professionals explains differences in innovative output among MSAs at the national scale of the United States, the same relationship is less clear when considered at the local scale of zip codes within particularly innovative MSAs.

Deficiencies in existing data sources were encountered by the research team during this project. As improvements are made in available sources, it may enhance the capacity of researchers in the future to more accurately identify regions with emergent technological capabilities:

- In 1982, the Small Business Administration (SBA) published a unique data set consisting of counts of actual innovations brought to market for which the geographic origin was given. The data were gathered from interviews and from exhaustive study of trade journals. Although the SBA innovation count database has proved a lasting resource, it has not been updated in more than 20 years. In the European Union and elsewhere, policymakers have moved forward aggressively to develop data infrastructures relevant to twenty-first century decisionmaking.

- The technological categories employed by the Census Bureau[1] are very useful for a coarse-grained assessment of economic activity. They match poorly to the core technology spaces, however, that define the strategic landscape for technology entrepreneurs, corporations, and, increasingly, regional planners. A capability to monitor the dynamics of core technologies both within the United States (as prototyped by this report) and internationally (from one region to another) may be developed in the future.

This report provides a starting place for specifying the types of data that could be collected and analyzed.

1. In particular, the Standard Industrial Classification (SIC) codes and the more recently developed North American Industry Classification System (NAICS) codes.

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1. Introduction

> [T]he nascent field of the social science of science policy needs to grow up, and quickly, to provide a basis for understanding the enormously complex dynamic of today's global, technology-based society… [R]esearch is necessary even to frame an approach. This is a task for a new interdisciplinary field of quantitative science policy studies.
>
> *—John Marburger,*
> *Director of the U.S. Office of Science and Technology Policy*
> *April 21, 2005, AAAS Forum on Science and Technology Policy, Washington, D.C.*

Political leaders and economic planners from Albuquerque to Zurich understand that the innovative capacities of people and institutions drive the economic vitality of regions. All regions have the potential to benefit from advances in the linked frontiers of science and of technology. The actual distribution of such benefits is affected by diverse factors: among them, public policy is potentially important. As a consequence, policymakers are challenged to find answers to the following question: *How can policymakers identify contemporaneously emerging geographical regions of technological activity that would be particularly responsive to public support and private investment?* This study provides an exploratory methodology and preliminary findings that may be useful to policymakers in response to this question.

Until recently, research on the spatial dimension of innovation processes has been impeded by computational constraints—by limits on the amount of geographical data that could be managed and visualized using generally available tools. Advances in network visualization and geographic information systems have relaxed computational constraints, and created an opportunity for renewed efforts in understanding regional innovation.

Effective policy formulation and program design require accurate, current, and comprehensible information regarding the characteristics of regional innovation systems over time. Effective policy and design also require indicators that assist in understanding the potential complementarities of public objectives and private incentives that can result in desired social outcomes. This project seeks to provide both the information and the relevant indicators. The project aims to provide the Advanced Technology Program (National

Institute of Standards and Technology, U.S. Department of Commerce), and the broader policy community with maps and related spatial analyses of regional innovative capacity constructed from a method that is (1) applied consistently across different spatial scales of analysis, and (2) based on an underlying model of the process of technology development.

Difficulties remain with attempting to identify regional communities that have an emergent capacity for technological innovation. Although this paper offers an exploratory methodology, there are at least three reasons lending difficulty to answer this question:

- First, measuring technological innovation is difficult. Patents are most often used as an innovation indicator. Patents measure invention (a novel technical idea with market potential), however, and not innovation (the successful application of that idea in markets). Furthermore, significant differences in the propensity to patent exist among different industries, and may also exist between process and product patents. Many innovations are not patented at all. Alternatives to patenting include intellectual property protection through copyright law or trade secret law, or development through an open source model.

- Second, hypotheses regarding the drivers of regional innovation are numerous and diverse, making it a challenge to rigorously test their individual impact. Statistical techniques exist that are capable of ordering the relative magnitude of correlations in complex, dynamic systems. Such techniques are complex and nontransparent, however, and consequently are potentially viewed with skepticism in a policy context by readers who are not technically trained.

- Third, the identification of the drivers of technological innovation is subject to what econometricians refer to as an endogeneity problem—the statistical version of the chicken-and-the-egg problem. Most drivers of regional innovative capacity are also affected by regional innovative capacity. For example, venture capital firms may drive a region's capacity for technological innovation, but they are also more likely to set up shop in, or relocate to, regions that already have a well developed capacity for regional innovation. Differentiating simple correlation (two phenomena are observed to occur at the same time) from causation (phenomenon number 1 causes phenomenon number 2) is also difficult.

1.1. DEFINITIONS

Invention, innovation, core technologies, and clusters

As in prior work,[1] we use invention as shorthand for a commercially promising product or service idea based on new science or technology that is protectable (although not necessarily by patents or copyrights). By innovation, we mean the successful entry of a new science- or technology-based product into a particular market. By early-stage technology development

1. Branscomb and Auerswald 2002; Auerswald et al. 2005.

(ESTD), we mean the technical and business activities that transform a commercially promising invention into a business plan that can attract enough investment to enter a market successfully, and through that investment become a successful innovation.

Because innovations must be novel, we restrict the definition of ESTD in the corporate context to products or processes that lie outside a firm's core business interests. The technical goal of ESTD is to reduce the needed technology to practice, define a production process with predictable product costs, and relate the resultant product specifications to a defined market.

A core technology space is a technological subdomain. A core technology may be defined by a particular patent or innovation, but then typically branches out in dozens of follow-on patents and innovations. An example is the transistor. Core technologies may link directly to products. In most instances, however, core technologies are employed to improve components of products or the processes used to make the products. Core technologies cut across conventional industry boundaries.

Emergent technology activity refers to a region's developing capability to perform early-stage technology development in one or more core technology domains. In contrast, a regional cluster is a collection of horizontally and vertically linked firms in a particular industry space. The manner in which we use the term cluster follows directly from Porter (1990, 1998), with refinements as proposed by Rosenfeld (2001). A given regional cluster may or may not be intensively engaged in early-stage technology development; however, all clusters attract specialized services, have open membership, and require both cooperation and competition.

Spatial scales of analysis

In our geographical analysis, we consider five distinct spatial scales. The largest two are the United States as a whole, and the 50 individual states that constitute the United States. These require no explanation. The region is the third largest of the spatial scales of analysis that we consider. By region, we mean a geographical unit of analysis comparable in scale to the Census Bureau's Metropolitan Statistical Area.[2] Because regions are economically rather than politically defined entities, they may cross state as well as national boundaries.

The city is a politically defined unit of analysis that is usually smaller than a region. The Washington, D.C., metropolitan area, comprising 25 subjurisdictions,[3] is roughly 100 times bigger in area than the city itself.

Finally, the zip code is a unit of analysis defined by the United States Postal Service. As a rule, zip codes are smaller in area than are cities—although that is not always the case.

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2. See http://www.census.gov/population/www/estimates/metrodef.html. We do not distinguish between enterprises in central city areas and those in nearby suburbs or industrially zoned areas.

3. In addition to the District of Columbia itself, the Washington, D.C., metropolitan area comprises 5 counties in Maryland, 2 counties in West Virginia, and five independent cities and 13 counties in Virginia.

At the base of this pyramid of distinct spatial scales is the street level address. The street level address provides the most finely grained unit at which spatial analysis of the type undertaken in this report can occur. From street level data, aggregate statistics at any of the larger scales of analysis can be constructed.

The word community is easily understood but hard to define with precision. Etzioni (1996) proposes a definition based on two characteristics: "(1) A community entails a web of affect-laden relations among a group of individuals, relations that often crisscross and reinforce one another (rather than merely one-on-one relations or chains of individual relations); and (2) community requires a commitment to a set of shared values, norms, and meanings, and a shared history and identity–in short, a shared culture." Communities may be defined geographically or may cross geographical boundaries. In this report, we focus on geographically concentrated communities (for example, in cities). Fostering innovation in communities thus means identifying communities in specific places with nascent technological capabilities whose development may be accelerated with public support.

1.2. ORGANIZATION OF THE REPORT

In section 2, we describe prior work and empirical challenges relating to the mapping of innovation. We then present a conceptual framework for data analysis. In section 3, we describe in detail the data sources used and the analytic approaches taken in the project. In section 4, we present our approach to identifying emergent regions. Section 5 offers our conclusions.

2. Why Map Innovation?

Cities are not new. Human population and economic activity have been concentrated for millennia. Cities have long been centers of innovation.[1] Population density facilitates personal contacts and trade. A diversity of factors and activities allows for cross-fertilization of ideas.[2] Scale allows for specialization.

What is new, in the past century, is the rise of science-based innovation and complex system development projects.[3] The introduction of new products in the twenty-first century, far more than in the past, involves overcoming both technical and market risks.[4] When products are based on truly novel technology or create new markets, their introduction often requires new organizational forms.[5] The knowledge that drives long-term growth in a modern economy is detailed, highly technical, and context-specific.[6]

The geographic distribution of science-based innovation roughly continues to mirror that of economic activity in general. This report undertakes to establish a credible methodology for identifying regions with emergent capabilities for science-based innovation, and more generally for tracking innovation flows and dynamics from one place to another.

Our focus is on innovation rather than growth. An ample literature demonstrates that vibrant regional innovation ecosystems benefit the economy and lead to broad improvements in human well-being. At different scales of analysis, the outcomes emphasized will differ. At the municipal level, the outcome of interest may be job creation; at the national level, economic growth; and at the global level, perhaps advances on the frontier of knowledge.

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1. Jacobs (1961, 1969) and Bairoch (1988).
2. Recent work by Ottaviano and Peri (2004) has provided new evidence for the economic value to regions of diverse populations.
3. See, for example, Rosenberg and Birdzell (1985). Schumpeter (1928, 1942) emphasized the emerging role of large corporations. Papers in Nelson (1962) emphasize this phenomenon. Trends in the last 20 years have belied Schumpeter's prediction of the demise of knowledge-intensive entrepreneurial firms. Auerswald and Branscomb (2005) discuss in detail.
4. Branscomb and Auerswald (2002).
5. Auerswald and Branscomb (2005).
6. Zeckhauser (1996).

Our interest is in understanding the characteristics of innovative capacity at a regional scale, and how those characteristics may change as the scale of analysis is varied.

The approach of this project combines state-of-the-art visualization techniques that can be applied across spatial scales (from the national to the street-address level), with statistical analysis of the determinants of regional innovative capacity at the scale of the MSA. It is novel in being both applied consistently across different spatial scales of analysis, and based on an underlying model of the process of technology development.

The results presented rely on a measure of innovative output for which data exist on a national scale. The approach makes use of a methodology developed by Tony Breitzman of CHI Research [7] that uses citation and co-citation information to identify *current* patents with potentially high commercial value. Previous approaches used to assess the value of current patents have relied either on the number of citations included in the patent, or the number of claims made in the patent. As discussed below, both of these prior approaches have been found to be problematic. The methodology and the manner in which it represents an improvement on prior work are explored below.

Although this project contributes new results, it is intended also to demonstrate the potential of new methodologies and to indicate the utility of near-term investments in data infrastructure that could support rationally designed and clearly targeted innovation policies. The project was motivated by a sense among the coauthors and the funding agency—consistent with the view of the Science Advisor to the President, represented in the quote at the outset—that the literature on regional innovation has suffered from incomplete data sources and a fragmentation of conceptual approaches. This report attempts to address both of these shortcomings by employing geographic information systems (GIS) methods to seek new and integrative modes of analysis—or at least new ways of organizing and looking at the data. Visualization creates new perspectives on dynamic and systemic aspects of innovation data that can be lost in purely statistical or mathematical analyses.

Figure 1 below is a model of the innovation process that displays the early stage between invention and innovation and the sequential relationships between the concepts (basic research to production and marketing).

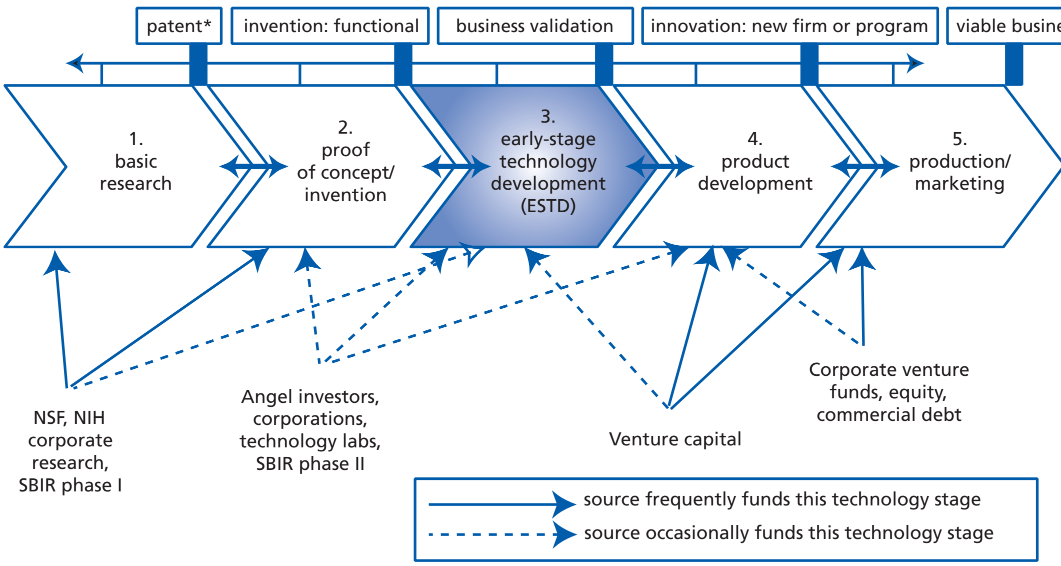
2.1. PRIOR WORK

Multiple and distinct literatures address the determinants of innovation at a regional scale. In recent decades, contributors have variously emphasized scale, specialization, diversity, and creativity. Data inadequacies, the slow diffusion of some relevant analytic techniques,[8] and the fundamental complexity of the underlying phenomena, however, have caused significant gaps in these literatures to remain.

7. This project was funded by the Economic Assessment Office of the Advanced Technology Program under NIST order number SB 1341-02-W-1156. Breitzman is currently the principal at 1790 Analytics.

8. In particular, the relevant ones are geographic information system (GIS) techniques.

FIGURE 1
Sequential Model of Development and Funding



Notes:
- The region corresponding to early-stage technology development is shaded.
- The boxes at top indicate milestones in the development of a science-based innovation.
- The arrows across the top of, and in between, the five stages represented in this sequential model are intended to suggest the many complex ways in which the stages interrelate.
- Multiple exit options are available to technology entrepreneurs at different stages in this branching sequence of events.

*A more complete model would address the fact that patents occur throughout the process.
Source: This figure was taken from Branscomb and Auerswald (2002, p. 33).

Agglomeration, knowledge spillovers, and localized networks

The seminal works on the structure of cities (for example, von Thünen 1826, Christaller 1933, Losch 1954, and Isard 1956) focused on locational choice, not technological innovation. In turn, the core work in economics relating to technology focused on the relationship between technological innovation and economic growth at a national scale—a different subject from the focus of this report. In early works, industrial districts were hypothesized to be the locales of what came to be termed the knowledge spillovers, contributing importantly to economic growth. Marshall (1890) is generally credited as being the first to comment on the benefits accruing within a given region or city to firms in the same industry from the informal exchange of tacit knowledge. In an oft-quoted passage, he writes: "Great are the advantages which people following the same skilled trade get from near neighborhood to one another. The mysteries of the trade become no mystery: but are as it were, in the air…."

Shell (1966) was the first to formally model economic growth resulting from public investments in research and development, where the level of technical knowledge is a public good. In recent years, economic theorists have explored the implications for growth and trade of the many different assumptions regarding the mechanisms by which knowledge spillovers occur. In most such models, knowledge of some type is aggregated into a single scalar or quantity. As a rule, knowledge networks are implicit, but are not explicitly represented.

The theoretical, mostly macroeconomic literature on knowledge spillovers has been complemented by an empirical, mostly microeconomic literature on localized networks and knowledge flows. The empirical literature has examined evidence for the existence of knowledge spillovers (see review by Griliches 1990), and measured the extent of their geographic localization.[9] A number of pathways for localized knowledge spillovers have been studied empirically, including learning directly from neighbors (Foster and Rosenzweig 1995), transfer of knowledge by star researchers (Zucker, Darby, and Armstrong 1998; Zucker, Darby, and Brewer 1998), and transfer of knowledge through buyer-supplier codevelopment efforts (Appleyard 2003). Renewed interest in the parallel phenomenon of agglomeration externalities has been sparked by the work of Arthur (1990) and of Krugman (1991a, 1991b), on concentrations of manufacturing activities resulting from positive feedbacks in the locational choices of new entrants (manufacturing production will tend to concentrate where there is a large market, but the market will be large where manufacturers' production is concentrated).

Specialized services, social networks, and collective entrepreneurship

A distinct but related branch of the literature focuses on regional innovative performance as related to the densely networked interactions of firms specializing in new firm creation. This idea is a common feature of work by Bahrami and Evans (2000), Kenney and von Burg (2000), and Owen-Smith and Powell (2002). In a detailed study of Silicon Valley social networks, Castilla et al. (2000) note that "[d]ense networks not only within but between sectors of engineers, educators, venture capitalists, lawyers, and accountants are important channels for the diffusion of technical and market information." These authors argue that innovation today is usually the product of many different types of entities working together.[10] The success of each of these institutional types—the metaphorical equivalents of species in an ecosystem—depends on the presence of others. Institutional species comprising a regional ecology of innovation are conjectured to include not only well recognized entities such as venture capital firms, large corporations, and universities; but also new forms such as angel networks, angel funds, university and corporate venture capital funds and incubators, experimental R&D programs supported by federal and state governments, fast track regulatory clearance services by state and local governments, and specialized service forms (for example, in law, real estate, or accounting).[11] Auerswald and Branscomb (2003) refer to

9. See, for example, Jaffe, Trajtenberg, and Henderson (1993), and Mansfield (1995).

10. Complementary to this line of argument is the classic work by Granovetter (1973) emphasizing the strength of weak (distant) ties; also relevant are recent studies by Watts and Strogatz (1998) and others on "small world" networks.

11. Suchman (2000) elaborates on the central role of lawyers in Silicon Valley as brokers of information.

the efforts to convert new knowledge into commercial innovations in such a context as collective entrepreneurship: it requires collaboration between people with different specialties and individual visions to achieve success.

Strumsky, Lobo, and Fleming (2005) aim to sort out the respective roles of urbanization (what we have referred to as agglomeration) and social networks as determinants of metropolitan inventive productivity, measured simply by patent output. Although they find that urbanization and social networks both matter for inventive activity, "inventor agglomeration is a much stronger determinant."[12] (Inventors are disproportionately agglomerated in larger metropolitan areas.)

Wallsten (2001) and Rosenthal and Strange (2001) are among the few to employ GIS techniques to study regional innovation. Wallsten (2001) finds that geographic impacts operate at an extremely short range: The number of Small Business Innovation Research (SBIR) Program award-recipient firms within one-tenth mile is a robust predictor, whereas the number of SBIR firms within one-half mile has no impact. Among SBIR winners, 17 percent are within one-tenth mile of another SBIR winner; 50 percent of SBIR winners are within one mile of another SBIR winner. Examining his findings, Wallsten conjectures that proximity allows informal conversations; that small companies are spun out of big companies, so stay close by; and that small firms tend to locate near each other because they have similar needs. To the extent that clustering encourages spillovers, then firms close to winners are more likely to apply.

Other literatures suggest alternative paths for advancing the understanding of regional innovation. In geography, a large and growing literature exists on infrastructure mapping—much of it appearing in unpublished government and commercial reports,[13] and concentrated on the physical and topological mapping of the Internet and the World Wide Web (WWW) (cybergeography). A related literature on complex networks has undergone a renaissance in the last five years.[14] Starting with the seminal work of Watts and Strogatz (1998), which explains the efficiency of large complex networks, researchers have examined the structural properties of many large real-world networks (for example, electrical power grids, disease transmissions, neural networks, the Internet, and food webs). These studies have found consistently that large real-world networks are efficient structures with high levels of clustering, featuring highly connected hubs, and are not random.

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12. The measure of inventive activity in the paper is simply U.S. utility patents granted. The measure of social networks is derived directly from data on the co-authorship of patents.

13. The key contributors to this literature are mainly commercial firms such as Platts, ESRI, Mapinfo, Geotel, KMI, and Telegeography, and government agencies such as USGS, CIA, NIMA, and DIA. Within academia there is some literature on infrastructure mapping, mostly in relation to the Internet; notable contributors include Martin Dodge, Matt Zook, Anthony Townsend, Angela McIntee, Ed Malecki, and Bill Cheswick.

14. Key contributors include Alberto Barabasi, Reka Albert, Duncan Watts, Steven Strogatz, Mark Newman, Alessandro Vespignani, and Jose Mendes.

Regional competitive advantage and clusters

The clustering of pathways in networks on certain highly connected hubs is part of a technical description of a network. An example would be the high number of citations received by certain academic articles or patents, when most articles and patents are not cited at all. A more general concept of cluster in the context of regional economic development is associated with Porter (1990, 1998, 2000).

Saxenian (1994, p. 57) proposes that regions are best understood "as networks of relationships rather than as collections of atomistic firms." The source of regional technological advantage lies in the tangible flexibility of economic actors to organize and reorganize as the need arises, and not in vague and unmeasurable knowledge spillovers. Saxenian stated in a 1998 interview comparing technology development in Silicon Valley with film production in Los Angeles: "You have these very fluid labor markets and these communities of highly skilled people who recombine repeatedly. They come together for one project—in this case a new film, in Silicon Valley it would be a new firm—and then they move on. The system allows a lot of flexibility and adaptiveness.… Information about new markets and new technologies flows very quickly. This sustains the importance of geographic proximity, despite the fact that, theoretically, the technology allows you to be anywhere" (Cassidy 1998, p. 125).

As emphasized by Rosenfeld (2001), networks and clusters represent quite distinct concepts. Although networks are closed and allow member firms to access specialized services at lower costs, clusters are open and serve to attract complementary specialized services to a region. Where networks are based on contractual agreements, clusters are based on values that foster trust and encourage reciprocity.

For centuries, particular regions have been recognized for their excellence in the production of certain goods. Glass making in Bohemia (Czech Republic), champagne in Rheims (France), and windmill production in Herning (Denmark) are but a few of the craft-based industries that offer historical examples of clusters.[15] In such regions, masters share tacit knowledge with apprentices, whose core capability lies in replicating centuries-old techniques.[16] New approaches are viewed by masters with suspicion, and are accepted into common practice only after considerable scrutiny.[17] Producers share access to specialized inputs in the production process, lowering marginal costs. The overall scale of production allows for specialization, which further increases productivity.

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15. Council on Competitiveness (2002) summarizes a comprehensive study of core economic clusters in five U.S. cities: San Diego, Wichita, the Research Triangle, Atlanta, and Pittsburgh. See <http://www.compete.org/pdf/national_execsummary.pdf>.

16. See also Porter (1990, p. 155).

17. Krugman (1991a, p. 54) describes a 1900 U.S. Census Bureau monograph entitled "The Localization of Industries," listing 15 U.S. industrial districts, including the following: collars and cuffs (Troy, New York); leather gloves (Gloversville, New York, and Johnstown, New York—neighboring towns); shoes (several cities in the northeastern part of Massachusetts); silk goods (Paterson, New Jersey); jewelry (Providence, Rhode Island); and agricultural machinery (Chicago, Illinois).

Porter (1990) represented the factors that drive the competitive strength of nations with a diamond model composed of four corners: favorable home market conditions; high-quality inputs to production; local competitive pressures encouraging excellence; and industry-specific linkages between suppliers and customers. The factors that drive cluster development exist in tension with the well-known factors that drive dispersion: high rents, potential increases in costs resulting from competition for shared inputs, and other forms of crowding.

Diversity and creativity

Jacobs (1961, 1969, and 1984) advanced the hypothesis that diversity, not specialization, is the key to vitality in cities. A pioneering empirical study of growth in a cross-section of U.S. cities by Glaeser et al. (1992) found that, at the city-industry level, specialization hurts, competition helps, and city diversity supports employment growth. Subsequent studies by Henderson et al. (1995) and Feldman and Audretsch (1999) conclude that economic diversity is important in explaining new firm creation and innovative output, respectively.[18] Working from a broader definition of diversity, Florida (2002a, 2002b) argues that the diversity of a region along cultural and other human dimensions suggests that communities at once tolerant and creative are the fundamental determinant of regional competitive advantage.[19] Florida (2002a, p. 220) states:

> The question is not whether firms cluster, but why. Several answers have been offered. Some experts believe that clustering captures efficiencies generated from tight linkages between firms. Others say it has to do with the positive benefits of co-location, or what they call "spillovers." Still others claim that it is because certain kinds of activity require face-to-face contact. But these are only partial answers. As I have already noted and will show in greater detail, the real force behind this clustering is people. Companies cluster in order to draw from concentrations of talented people who power innovation and economic growth.

By humanizing and refining impersonal concepts such as human capital and skilled labor, Florida offers an important contribution to the literature on regional innovation. Creativity and talent are themselves very general concepts. Additional work is required to better understand policy-relevant specifics of the process whereby a technical idea with potential commercial value is converted into one or more products ready for market.

Social capital, creativity, and other intangibles of place

Social capital encompasses the trust, norms, collaborative networks, and other features of social organizations that facilitate coordination and cooperation for mutual benefit. As constructed by Putnam (2000), social capital emphasizes institutions that facilitate frequent interactions and trust building. Focusing on innovation, Branscomb (1996) and Fountain

18. Quigley (1998) and Duranton and Puga (1999) survey this literature. Arora et al. (2000) studies at software clusters in Ireland and India.

19. In contrast, Olson (1982) argues that transactions costs are lowered, trust is enhanced, and economic activity is facilitated by cultural homogeneity. See Audretsch and Thurik (2001, pp. 16–17) for further discussion.

(1998) interpret social capital more generally, arguing that where strong social capital exists in a region, it substantially lowers the transaction costs involved in forming collaborative networks linking innovators, investors, producers, supporting service providers, and consumers with a common purpose and cooperative intent. It also enhances effective communications for shared decisionmaking. These collaborative networks encourage innovation by allowing regions to overcome the cultural, managerial, and institutional barriers that impede technology diffusion, productivity learning, and transfer of tacit knowledge.[20] In addition, network structures can more effectively adapt to environmental changes and more accurately identify critical information than can individuals or large institutions.

Work by Florida (2002a, 2002b) has further broadened the scope of variables considered relevant to the study of science-based innovation. In addition to conventionally considered determinants of regional innovative capacity, Florida has added indices to reflect the "coolness of a place" (the presence of a creative or bohemian class), cultural and recreational amenities, and the diversity of the population. In subsequent work, Florida sought more broadly to measure the extent to which people in a particular place are creative and tolerant.

2.2. EMPIRICAL CHALLENGES

Lessons from the empirical study of economic growth

Among economists, studies of the determinants of regional innovation have emphasized the use of econometric techniques. Challenges faced are reminiscent of those that have plagued empirical literature on the cross-country determinants of growth. Sala-i-Martin (1997, p. 5) comments:

> Almost all growth theories say that the "level of technology" … is an important determinant of growth…. A good theorist could make almost any variable affect the level of technology in this broad sense, and, as a result, he could make almost any variable look like an important theoretical determinant of the rate of economic growth. This is the same as saying that theory is silent when it comes to providing much guidance in our search for the "true" explanatory variables…. [E]ven if theory was clear in pointing to the important theoretical "determinants of growth," the empirical estimation of these determinants is not immediate. For example, we may have a theory that says human capital is important for growth. How do we measure human capital? There are lots of imperfect measures, and it is not clear a priori which one is better…. All of this has led empirical economists to follow theory loosely and simply "try" the various variables relating to the various potentially important determinants of growth.

A further challenge of estimating the relative significance of various factors driving industry clustering is differentiating endogenous factors (such as knowledge spillovers) from the local fixed effects that drive locational decisions (such as the legacy of particular institutions).[21]

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20. See Patel and Pavitt (1994).
21. Banerjee and Iyer (2002).

Lessons learned by empirical economists studying economic growth have not fully transferred to economists' study of regional innovation. The relevant academic literatures are replete with papers variously contending that the key determinant of regional innovative capacity is (inter alia) the strength of production networks, clusters, or both; the creative capabilities of workers; the local quality of life; the presence of research-oriented educational institutions; the existence of an entrepreneurial culture in the region; the intensity of federal procurement expenditures; or the presence of complementary and bridging institutions.

In the aggregate, these papers—many rigorous works of analysis—describe a system replete with complex interrelationships, feedbacks, and dynamic nonlinearities. Yet the literature on regional innovation is still beset by the theory and data problems described by Sala-i-Martin with regard to empirical literature on economic growth: a profusion of theoretically plausible models and a parallel profusion of potentially usable indicators.[22]

The literature associated with agglomeration externalities or knowledge spillovers has added greatly to our understanding of the way in which intraindustry complementarities and external economies can result in differences among regions in terms of innovative activity. The capacity of individual regions, however, to sustain innovation across a variety of fields has differed greatly. As Fogarty and Sinha (1999) and Leslie (2001) have demonstrated, neither past technological leadership nor large current investments in knowledge creation are sufficient to create a sustained capacity to innovate at a regional scale. The literature on agglomerations has not answered questions such as why industry-specific regional advantages have failed to persist indefinitely; why some cities and regions that lead in particular industries or benefit from a strong research infrastructure persistently lag in terms of their innovative output; nor why the most innovative urban areas appear to feature a high degree of diversity in business capacity and experience.

Lessons from the policy literature

Local governments, nonprofit organizations, and consultants have produced numerous city-level (or MSA-level) comparative analyses of innovative capacity and performance. Notable among these are the Milken Institute (2001, 2003), the Progressive Policy Institute (2001), and Reamer et al. (2003). These studies have advanced policy discussions by emphasizing the variety of determinants of regional innovative capacity. The list of variables included in the Progressive Policy Institute's (2001) "Metropolitan New Economy" (MNE) index, as shown in Box 1, is representative.[23]

Although the Progressive Policy Institute study and the others referenced have contributed significantly to policy discussions on regional innovation, they share some prominent

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22. The work of Sala-i-Martin (1997) attempted to test the robustness of various determinants of growth rates of per capita GDP among countries.

23. For an example of state-level data, see U.S. Department of Commerce (June, 2000).

BOX 1

Progressive Policy Institute's "Metropolitan New Economy Index"

The weight given to the variable in the index is given in parentheses.

Knowledge Jobs (2.0)

- Professional, Managerial, and Tech Jobs (1.0)
  Source: Managerial, Professional, and Tech Jobs: Bureau of Labor Statistics, Current Population Survey, 1999.
- Workforce Education (1.0)
  Source: Degrees: Bureau of Labor Statistics, Current Population Survey, 1998.

Globalization (1.5)

- Export Focus of Manufacturing (1.5)
  Source: Manufacturing Exports: International Trade Administration, U.S. Department of Commerce, 1998. All figures show sales by exporters of record located in indicated area. (http://www.ita.doc.gov/td/industry/otea/metro)

Dynamism and Competition (3.0)

- Gazelles [rapidly growing small firms] (1.0)
  Source: David Birch, Anne Haggerty, and William Parsons, Corporate Demographics: Corporate Almanac (Cambridge, Mass.: Cognetics, 1999), p. 59. This indicator shows the number of people employed by gazelle firms in 1998 as a share of total establishment employment (an establishment is defined as a place of work, a physical location).
- Job Churning (1.0)
  Source: Loss rate: David Birch, Anne Haggerty, and William Parsons, Corporate Demographics: Corporate Almanac (Cambridge, Mass.: Cognetics, 1999), p. 40. Gain rate: David Birch, Anne Haggerty, and William Parsons, Corporate Demographics: Entrepreneurial Hot Spots (Cambridge, Mass.: Cognetics, 1999), pp. 24–28.
- New Publicly Traded Companies (1.0)
  Source: Securities and Exchange Commission, EDGAR-ONLINE, 1999 and 2000.

Digital Transformation (4.0)

- Online population (1.0)
  Source: Adult Internet Penetration: Scarborough Research (New York: October 18, 1999) (http://www.scarborough.com).
- Broadband Telecommunications Capacity (0.75)
  Source: Broadband providers per zip code: Federal Communications Commission, High Speed Service Providers as of 12/31/99 (Washington, DC.: 2000). (http://www.fcc.gov/Bureaus/Common_Carrier/Reports/FCC-State_Link/comp.html)
- Computer Use in Schools (0.5)
  Source: Children using Internet in the classroom: Bureau of Labor Statistics, Current Population Survey, 1998.
- Commercial Internet Domain Names (1.0)
  Source: ".coms": Zook, M.A. (2000) "The Web of Production: The Economic Geography of Commercial Internet Content Production in the United States," *Environment and Planning A.* Vol. 44, No. 10. (http://www.zooknic.com/) 1999 data.
- Internet Backbone (0.5)
  Source: Bandwidth: Data compiled by Edward J. Malecki, University of Florida, from the Directory of Internet Service Providers, 12th Edition, (Golden, Colo.: 2000).

Innovation Infrastructure (4.0)

- High-tech Workers (1.0)
  Source: High-tech employment: U.S. Census Bureau, County Business Patterns, 1997.
- Degrees Granted in Science and Engineering (0.75)
  Source: Degrees: National Science Foundation, CASPAR Database, 1996.
- Patents (0.75)
  Sources: Patents: U.S. Patent and Trademark Office. Data are for utility patents, 1998.
  Source: Academic R&D: National Science Foundation, CASPAR Database, 1997.
- Venture Capital (0.75)
  Source: Venture capital: Pricewaterhouse Coopers LLP, Money Tree Report 1999 (Boston, Mass.: 1999).

Additional data sources: Overall 1998 employment: U.S. Department of Commerce, Bureau of Economic Analysis (BEA), Regional Economic Information System. Gross metropolitan product: U.S. Metro Economies: The Engines of America's Growth (Lexington, Mass.: Standard & Poor's DRI, 2000).

shortcomings. First, the Progressive Policy Institute includes each of the variables in the MNE index with reference to the literature, but the collection is fundamentally ad hoc. The usefulness of the rankings to assess the effectiveness of specific policy outcomes is limited by the lack of a coherent underlying model linking individuals, institutions, and incentives to observed outcomes. Second, with few exceptions, the analysis in these and similar studies is based on aggregate data.[24] As a consequence, it is not possible to follow up on these studies with more finely grained analyses of the innovative process (for example, at the scale of the neighborhood, the firm, or the technology project). Third, because the analyses are fundamentally retrospective, they may reinforce the tendency of local policymakers to follow "me-too" approaches to regional development.

Lessons from the program evaluation literature

Ruegg and Feller (2003) present models, methods, and findings from 10 years of program assessment at the Advanced Technology Program—a field in which ATP established a leadership position in the U.S. government during the 1990s. The ATP assesses overall program effectiveness by aggregating and integrating project-level measures of success. Monitoring outputs is challenging in itself, due, for example, to potentially divergent ATP and firm operational definitions of project. The ATP seeks to go further by identifying and quantifying causal relationships between firm-level outputs from ATP-funded projects and the related societal outcomes and impacts.

As discussed in Ruegg and Feller (2003), a challenge in any evaluation effort is to find measures of success related to the program's goals. Appropriateness of a measure competes with data availability as the key criterion in determining which potential measures are used in program evaluation. Often, programs and policies are evaluated based on different goals than those initially set forth. For example, in evaluating the usefulness of research parks as an economic development tool, Wallsten (2004) uses as an outcome measure the growth in venture capital activity. The contention is that, since venture capital is associated with strong regional technology clusters, and communities establish research parks to create technology clusters, it follows that the creation of a research park should result in more venture capital. Communities establish research parks, however, with multiple and varied goals, and increasing the local level of venture capital activity is rarely the most important one.

2.3. CONCEPTUAL FRAMEWORK

Our conceptual framework builds on prior EAO-funded research on the sources of funding of early-stage technology development (Branscomb and Auerswald, 2002). That report began with the dual observations that (1) technological innovation is critical to long-term economic growth, and (2) the core driver of technological innovation is the capacity to turn inventions into innovations. Understanding this transition is critical to the formulation both of public

24. The San Diego planning study provides a detailed appendix describing this process <http://www.sandag.org/programs/economics_and_finance/regional_prosperity/pubs/app_d.pdf>.

policies and private business strategies that are designed to make conversion of the nation's research assets into economic assets more effective.

Figure 2 places the invention-to-innovation transition in a local and regional geographic context.

The innovation system exists in the context of public policy, the economic environment, and other intangibles. The economic context is largely shaped by private actors. Economic variables that reciprocally affect the innovation process include both standard macroeconomic indicators (for example, gross domestic product [GDP], balance of payments) at national and regional levels; consumer confidence and preferences; the knowledge base of the economy (in people, equipment, and on paper); the strength and reliability of institutions; and culture, particularly attitudes about educational achievement and risk taking. Policy measures that most directly affect science-based innovation include tax and fiscal policies, antitrust policy, education policy, and policies concerning the protection of intellectual property.

Advances in fundamental knowledge—basic science on the left-hand side of the figure—undergird the innovation system in a modern economy. In the United States in 2002, public and private entities invested $50 billion in basic research. Although debate occurs over the adequacy of current levels of basic research funding, few question the premise that government has a central role in supporting the advancement of science.

Of course, advances in basic science will have no impact on economic growth or human well-being if they do not translate first into technologies, and ultimately into goods and services. The core technologies represented in the second column of Figure 2 are the direct translation of science into a capability for innovation. Core technologies may be developed within the university, in an entrepreneurial start-up, or, most commonly, in the existing corporation. Developers of core technologies may seek intellectual property protection in different ways, notably including patent protection.

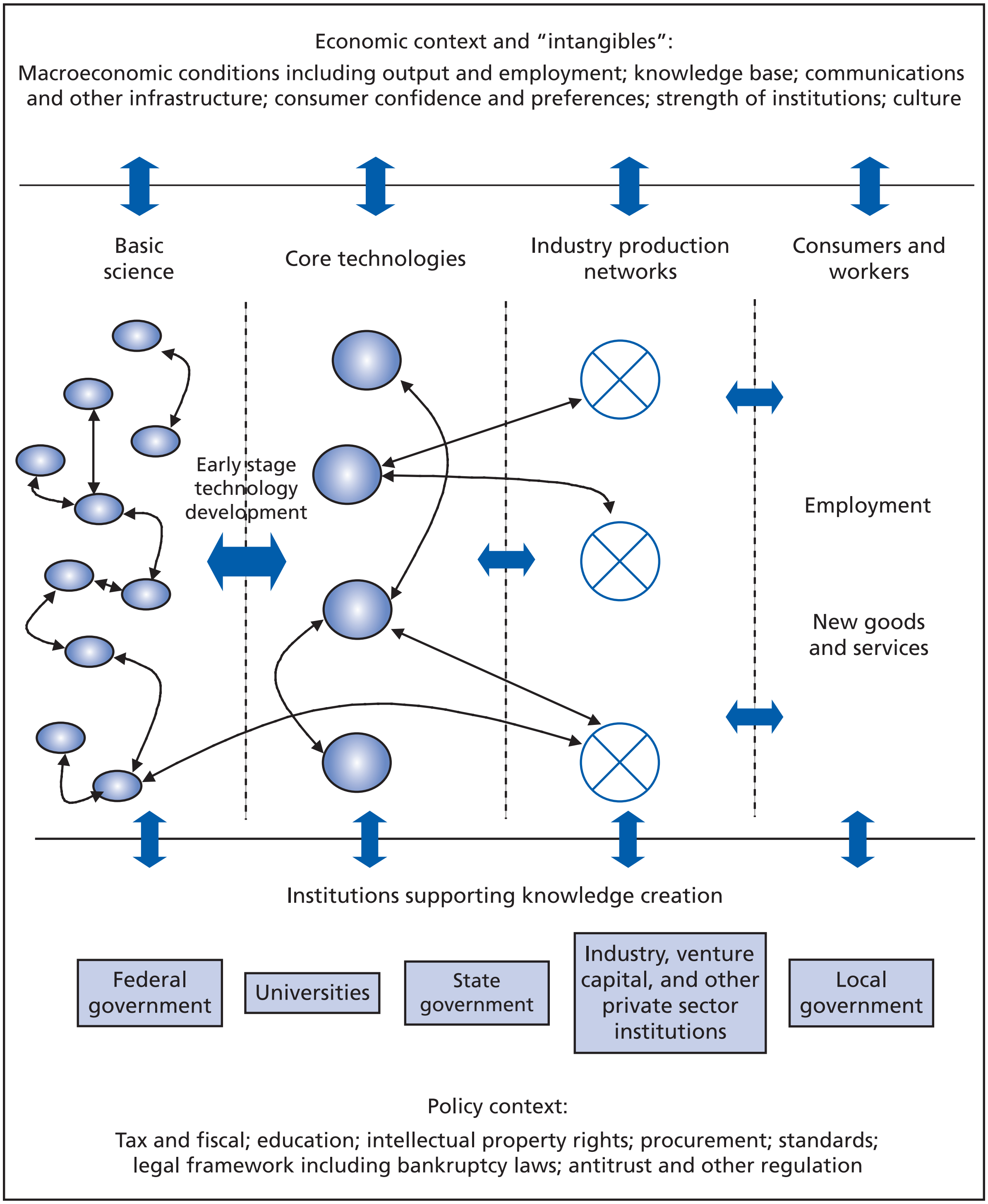
Core technologies typically are combined to create new goods and services. Industry production networks organized around existing goods and services are represented in the third column from the left in Figure 2. When industry production networks are localized, they form clusters of the type described by Porter (1990, 1998, 2000). It is important to emphasize that clusters in this sense are defined in terms of goods and services, not in terms of technologies. Clusters and production networks are discussed in greater detail in the following section.

2.4. POLICY VARIABLES

In general terms, local, state, and national governments can support technology entrepreneurs primarily by facilitating the existence of a stable economic environment in which transactions costs are low, contracts are enforced, and resources are transferred

FIGURE 2

Representation of the Complex Network of Resources, Capabilities, and Institutions that Sustain a Region's Innovative Capabilities



Source: Derived in part from Auerswald 2001.

efficiently. Government may also support science-based innovation and the efforts of technology entrepreneurs in five distinct ways:

- *Intellectual property protection.* Patent and trade secret laws protect innovators and, in theory, provide incentives for the development of new products, processes, and services. The reality that innovators operate in is increasingly complicated, as has been documented by Jaffe and Lerner (2004). Because intellectual property protection is largely a function of policy at the federal level, with significant discretion left to the states, it is not treated in this project.

- *Financial resources.* Governments may provide financial support to technology entrepreneurs through both direct and indirect financial assistance. Direct assistance may take the form of grants or contracts for the conduct of research aimed at potential commercialization. Indirect assistance may take the form of R&D tax credits. It may also take the form of subsidies to private entities seeking to develop pools of resources to lend to entrepreneurs.

- *Physical infrastructure.* Localities may provide technology entrepreneurs with physical space, equipment, communications infrastructure, access to transportation facilities, or other physical infrastructure.

- *Services.* Localities may also provide services directly to entrepreneurs. Such services may include market research, business development assistance, legal assistance, and facilitation of networking.

- *Attracting large technology-related organizations.* In a technologically lagging MSA, local, state, and federal governments may act in different ways to direct or encourage the location of large-scale research, educational, or production facilities (both public and private). Such policies are usually pursued on the basis of job creation, rather than as a component of policies to assist technology entrepreneurs. In some cases, however, the presence of large technology-based organizations may serve to encourage the development of small firms in the region that provide services or technology to the large institution. In other cases, the net impact on technology entrepreneurship could be negative—the large institution could act as a sink for local talent. Along the same lines, however, the large institution ultimately may act as a reservoir of technology spin-offs in the region.

The domain of policy instruments actually used in the United States during the period of study is huge. Our focus on the use of GIS methods in this project allowed us to narrow the domain considerably by leaving aside policy instruments whose impact was uniform over entire states or the nation as a whole. Within the subdomain of localized policy instruments, we selected three to be representative of financial and physical resources, respectively:

- *Business incubators.* In the category of physical infrastructure policies, business incubators are particularly well defined geographically. Although equipment can be moved, as a rule, buildings cannot.

- *Small Business Innovation Research awards.* Awards from federal agencies through the SBIR program fall into the category of direct financial resources provided to technology entrepreneurs. SBIR awards are of two types: Phase I ($100,000) and Phase II ($750,000). The SBIR program was initiated in 1982. We consider awards from 1992 through 2002.

- *Advanced Technology Program grants.* Although it is also a program that awards funds to technology entrepreneurs in a competitive process, ATP differs from SBIR in important respects. Two are worth highlighting: (1) ATP awards are considerably larger than SBIR awards, and (2) ATP awards are focused on technology development rather than on firm development, so large firms are not restricted, but are also eligible to compete. Data used in this study cover all award years.[25]

We did not identify a database usable to reflect policies aimed at providing services directly to entrepreneurs.

By narrowly restricting the set of policy instruments included in our data set, we predetermined that we would have few, if any, significant results with regard to policy as a determinant of regional innovation. The current study establishes the context for potential future analysis of the marginal impact of policy in generating science-based innovation; it does so by exploring correlates between innovation inputs (including policy) and innovation outputs. As indicated previously, further study is needed to consider a more complete array of policy instruments and subsequently to establish their relative impact on innovation outcomes.

2.5. ANALYSIS

The research took place in three stages. In the first stage of the project, we identified data sources and the data to be collected; established a methodology for analyzing the data; collected sample data; and performed preliminary data analysis. Guided by the conceptual framework sketched in Figure 1, the project team sought modes of visualizing the data that would enhance the understanding of regional innovation systems.

In the second stage of the project, we completed the data collection based on the priorities established in phase 1. Because we were attempting to use GIS tools in this project to produce visualization of the data, we were required to geocode all data sources that we planned to use. We then considered the data we gathered from many angles, by generating a variety of maps and exploring correlations between included variables to gain insights regarding phenomena of particular interest.

In the third and final stage of the project, we selected those mapping approaches that we felt yielded the greatest insights regarding the nature of regional innovation in the United States. We undertook initial work to differentiate between leading candidate hypotheses regarding

25. In the aggregate, ATP funding is a tiny fraction of SBIR.

the drivers of regional innovation. As a first step to gaining a deeper understanding of the factors that may contribute to or hinder the innovative capacity of a region, we calculated pairwise correlation coefficients for key variables. In this analysis, we used data from ESRI Business Analyst (2001) to describe the economic and social characteristics of each MSA, data on ATP recipients, SBIR recipients, and incubators as policy variables. We also used frequently and recently cited "hot" patents and the emerging technology patents that cited them as measures of innovation data. We describe each of these data sources in detail.

3. How We Chose the Variables in the Study

The literature reviewed previously suggests an array of potential variables that could be used to identify regions with emergent technological capabilities. Data surveyed for this project were from both public and commercial sources. We had three criteria for selecting those variables ultimately used for the study:[1]

- First, we required that the variables plausibly measure one of the innovation correlates suggested by theory. Links between the specific variables chosen and the four primary classes of theory under consideration in the study are detailed immediately below.

- Second, we required that any data set used in the study include a detailed geographical identifier—ideally a street level address, but alternatively a zip code or a county.[2]

- Third, we sought to include data sources that are gathered consistently every year, allowing for the approach developed to be extended and further tested by future study.

We selected 26 variables to represent four categories of innovation correlates as follows:

Innovation infrastructure: The most obvious correlate of future success in innovation is past success. The legacy of past success (or past investment) in a region is a well-developed innovation infrastructure: venture capital firms, patent lawyers, research facilities, and information technology firms.[3] The emphasis on infrastructure is motivated generally by the various knowledge spillover and network theories of innovation surveyed previously. It is also motivated by research emphasizing the manner in which complementary institutional

1. An obvious problem is that the data are not all for the same year, and differences could occur when variables represent a variety of time periods. Regions and institutions can change over time, although these changes occur slowly.

2. Specifically, we restricted our attention to data sets that either had already been geocoded, or could be geocoded without extensive gap-filling. Geocoding refers to the association of data points with longitude and latitude coordinates, enabling the use of GIS mapping software. Details of this process are given in Appendix A.

3. Of course, not all information technology firms are innovative. There are many companies that design Web sites that are not part of the innovation infrastructure.

types are required for innovation at the regional level (for example, Bahrami and Evans [2000], Kenney and von Burg [2000], Owen-Smith and Powell [2002], and Auerswald and Branscomb [2003]).

- *Variables*: **engineering services, IT software companies, physical research facilities, patent lawyers, testing laboratories, universities and colleges (restricted to those with more than 1,000 employees),**[4] **venture capital firms,** and **venture capital recipient companies.**

Social capital: Various observers (including Branscomb [1996] and Fountain [1998]) have noted that trust is important to the conclusion of contracts involving high degrees of uncertainty or potential incompleteness. Putnam (2000) popularized the notion that levels of social capital, reflecting the presence of trust and shared values within a community, could be measured through membership in certain institutions, including bowling clubs, business associations, and civil social organizations. This work motivates the social capital variables employed in the study. Rather than membership rates, we employ counts of institutions.

- *Variables*: **bowling centers,**[5] **business associations,** and **civil social organizations.**

Creativity and culture: A third body of work emphasizes the fundamental role of creative professionals in regional economic development. The conjecture advanced by Florida (2000a, 2000b) is that creative professionals of various types seek to locate near other creative professionals, and that this process of collocation and subsequent interaction is a key driver of economic and innovation outcomes in regions. As a consequence of this dynamic, regions that are more diverse and tolerant will be more innovative (all else being equal). As creativity and culture are broad notions, we consider three subcategories of establishments: religious organizations, art and craft organizations, and professional creative service providers.

- *Creativity and culture variables—art and performance*: **museums and art galleries, live band/orchestra,** and **live theater.**
- *Creativity and culture variables—reading and crafts*: **bookstores** and **hobby shops.**
- *Creativity and culture variables—religion*: **religious organizations.**
- *Creativity and culture variables—professional services*: **architectural services, management consulting,** and **management services.**
- *Creativity and culture variable—disamenity*: **racetracks** (includes auto, horse, and greyhound racetracks) and **correctional facilities.**

4. This is a proxy for research schools.

5. The inclusion of counts of **bowling centers** as a variable is motivated directly by the title of Putnam (2000). By including this variable we are not suggesting that technology entrepreneurs are systematically striking deals or exchanging ideas about new technologies at bowling alleys. A more correct statement of the underlying hypothesis is that large numbers of bowling alleys could reflect a local strength of bowling leagues, which in turn would be indicate robust social capital.

Economic context and public policy: Finally, and importantly, we considered a set of variables that described the economic context for innovative capacity, including public policy. The sources for these variables are described below in section 3.1.

- *Economic context and policy variables*: **ATP awards, incubators, population, physical research, SBIR Phase I and Phase II awards,** and **university and college R&D funds (dollar amounts).**

Innovation indicators: The innovation indicators employed in the study are described in detail in section 4, below.

3.1 DATA SOURCES

Because of our requirement for detailed geographical identifiers, the variables we used in the work as reported were primarily counts of business and organizational entities derived from the ESRI Business Analyst, a commercial database used primarily for marketing and demographic analysis:[6] ESRI Business Analyst categories follow the North American Industry Classification System (NAICS) from the U.S. Bureau of the Census.[7] The year of the version of ESRI Business Analyst we used in the study is 2003.

The variables drawn from ESRI Business Analyst are as follows: **architectural services, bookstores, bowling centers, business associations, civil social organizations, correctional facility, engineering services, hobby shops, IT software companies, live band/orchestra, live theater, management consulting, management services, museums and art galleries, physical research facility, racetracks, religious organizations, testing laboratories,** and **universities and colleges (more than 1,000 employees).**

The sources for the remaining data are as follows:

- **Advanced Technology Program awardees:** List of awardees from the U.S. Department of Commerce, National Institute of Standards and Technology, Advanced Technology Program.[8]

- **Business Incubators:** 2005 list of member organizations from the National Business Incubation Association.[9]

- **Patents**: Data from the U.S. Patent and Trademark Office, organized by CHI Research in the manner described in section 4 below.

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6. See < http://www.esri.com/software/arcgis/extensions/businessanalyst/index.html>.
7. NAICS definitions relating to variables used in this study are given in Appendix A. For further information on NAICS, see < http://www.census.gov/epcd/www/naics.html>.
8. See <http://www.atp.nist.gov/>.
9. See <http://www.nbia.org/>.

- **Patent lawyers:** 2004 list of patent lawyers in the United States from the U.S. Patent and Trademark Office.[10]

- **Population:** 2002 U.S. Population data from the U.S. Bureau of the Census.

- **Small Business Innovation Research (SBIR) Program awardees**: 1992–2002 recipients of SBIR Program awards from the Small Business Administration.[11]

- **University research funding:** 2002 U.S. university research and development expenditures from the National Science Foundation, "Academic Research and Development Expenditures, Fiscal Year 2002."[12]

- **Venture capital firms and venture capital recipient companies:** Data from the Venture Source database on U.S. venture capital firms that made investments in U.S. firms from January 1990 to August 2005, and on the companies that received the investments. Data restricted to 1,719 venture capital firms active (that is, with some assets under management) in 2005.[13]

3.2. NORMALIZING THE DATA TO ACCOUNT FOR DIFFERENT POPULATION LEVELS

Population is one of the most fundamental variables describing economic context. To begin with, population defines metropolitan areas. That population is highly concentrated is the starting point for any study of economic geography. Data on population density are used to define Metropolitan Statistical Areas, the primary aggregate unit of analysis used in this report. The concentration of population is evident in Figure 3 (below), a "heat map" of the distribution of population in the United States. Multiple population centers are displayed.

Population affects the innovation process in multiple ways. A region with a large population is also likely to be characterized by high overall levels of economic activity. The region is also likely to contain in abundance human inputs into the innovation processes—entrepreneurs, Ph.D.s, lawyers, and managers. High population density (persons per square mile) may also indicate a relatively high probability that people will meet and exchange ideas. The high correlation of population overall and the concentration of inventors is evident when comparing or superimposing Figures 3 and 4, a heat map which then also shows the concentration of U.S. patent holders (we use the term inventors).

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10. See <http://des.uspto.gov/OEDCI/>.
11. See <http://www.sba.gov/SBIR/>.
12. See <http://www.nsf.gov/statistics/rdexpenditures/>. We thank Paul Fowler for assistance in generating geographical identifiers for the data set.
13. Total number of venture capital companies in the database is 4,558.

FIGURE 3

Population Density by Cities (2002)

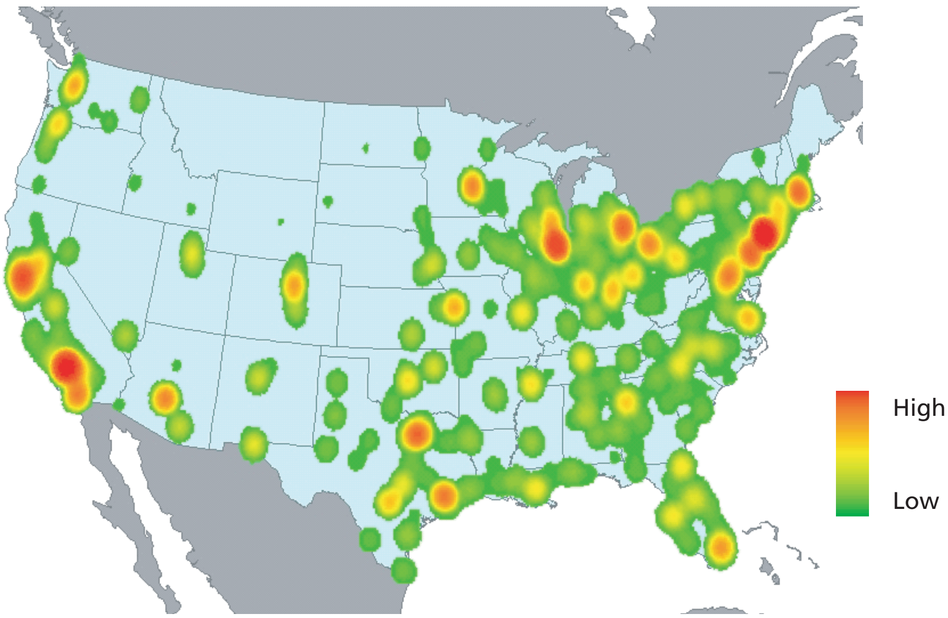
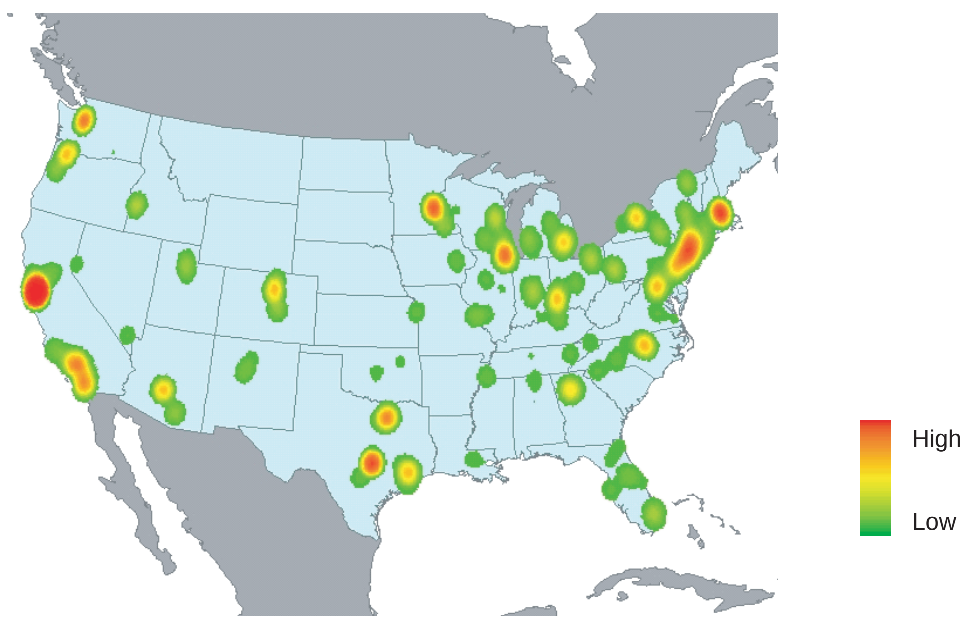


FIGURE 4

Inventor Density by Cities (2002)



Normalizing for population is the first step toward the sensible comparisons of the innovative capacities of different regions. The number of inventors per capita by city (Figure 5) reveals that, despite the high correlation of population with numbers of inventors, the concentration of inventors is far greater in some places than in others. Although invention occurs throughout the country, the per capita distribution of inventors is quite concentrated on the two coasts. Expected hubs around Austin, Texas, Denver, Colorado, and Los Alamos/Santa Fe, New Mexico, are also evident. Even this simple map, however, reveals some surprising facts about the distribution of innovative activity, particularly the very high per capita concentration of inventors centered in Cincinnati, Ohio. An examination of the data reveals that Cincinnati is home to 730 inventors listed first on a total of 1,207 patents. Of these, fully 832 belong to Proctor & Gamble. Other large corporations also hold large numbers of Cincinnati-listed patents: General Electric is responsible for 50; Merrell Dow Pharmaceuticals and other pharmaceutical companies (such as Ethicon Inc.) hold nearly 100 among them. The surprise turns out to be no surprise at all: large corporations are responsible for a significant share of the nation's patents.

Venture capital firms and the companies that receive venture funding are far more concentrated on the two coasts than are patent recipients, as shown in Figures 6 and 7. The number of venture capital firms in a given city ranges from a minimum of 0 to a maximum of 276. For firms receiving venture capital disbursements, the range in number of firms is from 0 to 5,291 . In Figures 6 and 7, metropolitan regions are identified by a square of the size and color that corresponds with the number of VC firms and recipient companies observed. A method of equal-intervals is used to differentiate regions, which permits the

FIGURE 5

Inventors per Capita, by City (2002)

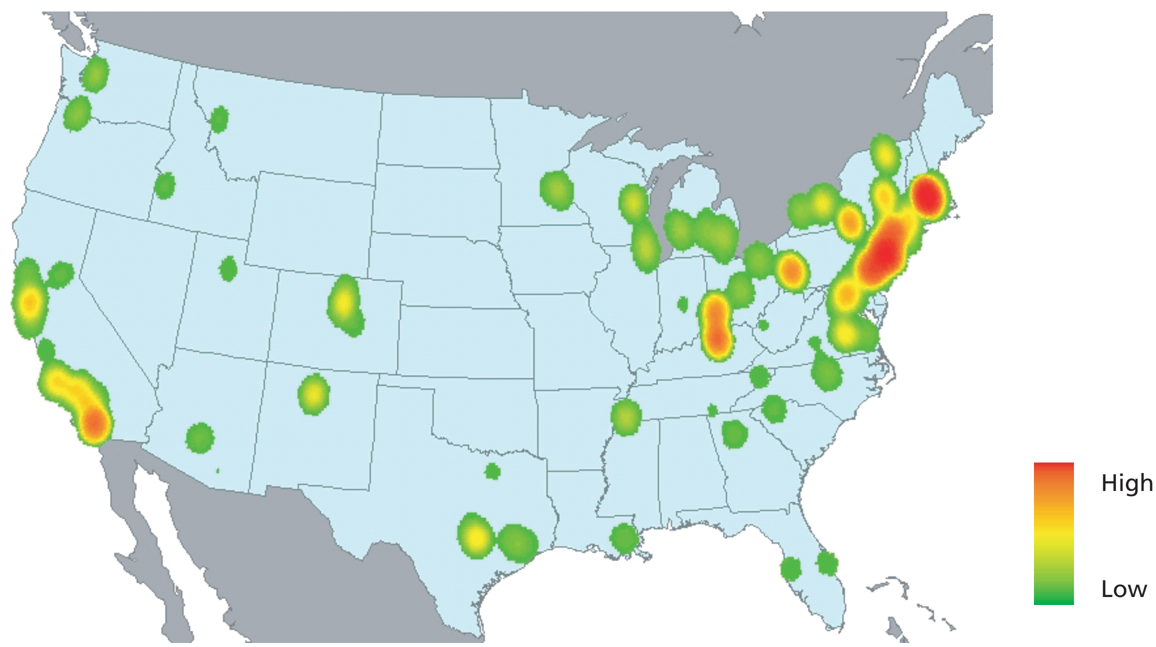


FIGURE 6

Cities with High Concentrations of Venture Capital Firms (2002)

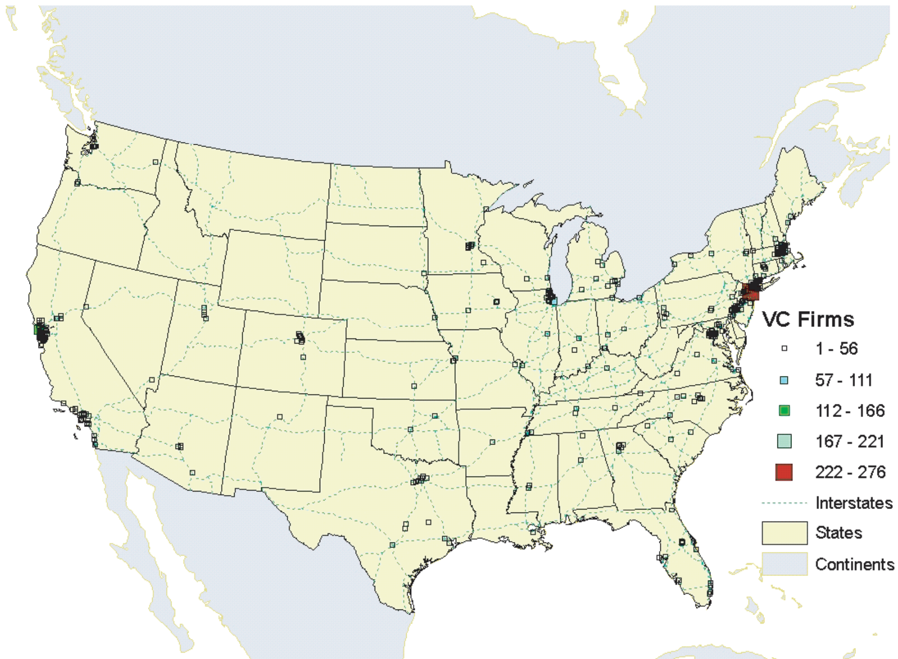
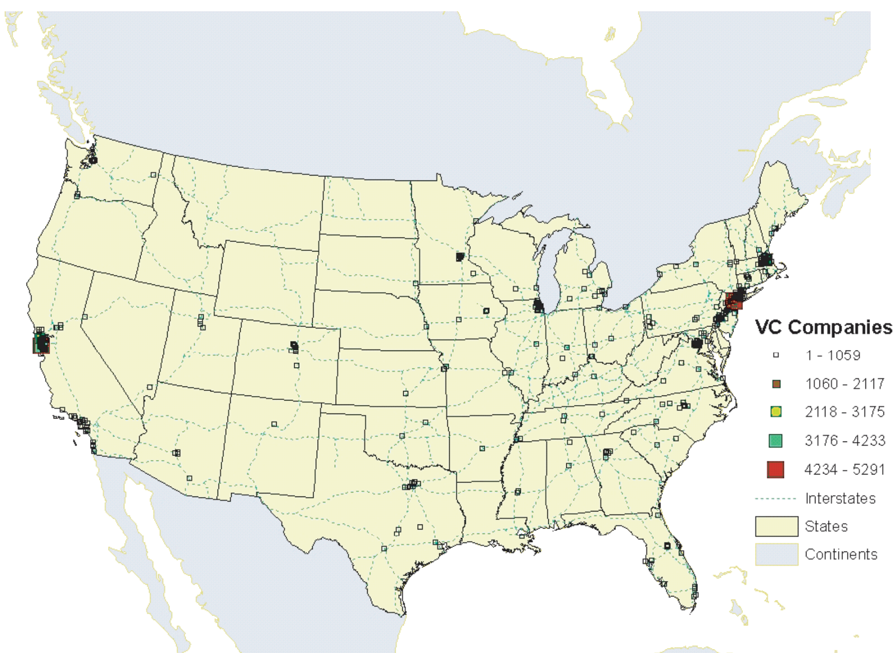


FIGURE 7

Cities with High Concentrations of Venture Capital Recipient Companies (2002)



skew in the data to be easily observed: There are far fewer regions with large numbers of venture capital firms and recipient companies (in Figures 6 and 7, the red squares represent the top quintiles) than there are regions with moderate and lower numbers of venture capital firms and recipient companies (the different sizes of green squares represent the lower quintiles). For example, in the case of VC firms, only New York is in the top quintile, and for VC recipient firms, only Palo Alto and New York are in the top quintile.

4. Identifying Emerging Technology Regions

The previous section sets the context for the report. It describes the variables that were used in the project to differentiate between technology regions, and also describes the importance of normalizing the data with regard to population. In this section, we address the difficult challenges of measuring innovation outcomes.

4.1. THE PARTICULAR CHALLENGE OF MEASURING INNOVATION OUTCOMES

Unlike the cross-country study of economic growth, which straightforwardly seeks to explain variations in conventionally measured GDP, the study of regional innovation is complicated by the absence of reliable outcome measures.

Patents are the most frequently utilized proxy for innovation outcomes. Acs et al. (2002) summarize the problems with using patents as a measure of innovation outcomes:

> Although patents are good indicators of new technology creation, they do not measure the economic value of these technologies (Hall et al. 2001). According to Griliches (1979) and Pakes and Griliches (1980, p. 378), "patents are a flawed measure [of innovative output] particularly since not all new innovations are patented and since patents differ greatly in their economic impact."

Significant differences in the propensity to patent exist among different industries, and may also exist between process and product patents. In the same technology domain, the rate at which patents are filed may vary systematically as a function of the path of technology development.[1] Furthermore, many innovations are not patented at all. Alternatives include intellectual property protection through copyright law or trade secret law, or development through an open source model.

1. See Powell and Moris (2002) for a discussion of interindustry differences in technology timelines. We are grateful to Egils Milberg for suggesting to us the potential relationship between technology development curves and patenting rates.

Acs et al. (2002) seek to evaluate the reliability of patents as a proxy for innovation outcomes. Using a 1982 literature-based innovation count database developed by the SBA, the authors seek "to provide some insight into the reliability of the patent data as a proxy for regional innovative activity (a second-best solution)." While their econometric findings show that patents are a good proxy for innovations in the market, the raw data analysis in the paper establishes that regions differ dramatically in their ability to convert inventions into innovations. A striking contrast exists between Albany/Schenectady/Troy (innovations/patents ratio = 0.0034, lowest among all MSAs with 100+ patents) and San Jose/Silicon Valley (innovations/patents = 0.57, highest among all MSAs with 100+ patents). The other MSAs that were considered fell in between: Boston (innovations/patents = 0.35); Cleveland (innovations/patents = 0.18); and Washington, D.C. (innovations/patents = 0.13).

A series of groundbreaking papers by Audretsch and Acs, leading to more recent work by Feldman and Audretsch (1999), and Acs et al. (2002), made use of a unique data set first published by the Small Business Administration in 1982 and updated in 1984. (See Gelman Research Associates Inc. [1982] and Futures Group [1984] for a detailed description.) The data set consisted of counts of actual innovations brought to market for which the geographical origin was given. The data were gathered from interviews and from an exhaustive study of trade journals.

While the SBA innovation count database has proved a lasting resource, it has not been updated in 20 years. For this reason, we did not consider it to be suitable for use to measure innovation outcomes in this project.

As an alternative, we considered using a measure based on R&D 100 Awards recipients. We envisioned that this data set could be offered as a direct measure, regularly maintained, of innovation outcomes. We continue to believe there is promise in this approach, as the R&D 100 Awards has a long history, during which time the methodology for selecting award recipients has undergone few changes. In studying the data set, we noted that the balance of recipients of this award, however, had shifted over 40 years away from private firms and toward the national laboratories, most of which are located in geographically remote areas. Without exploring the reasons for this shift—including, possibly, an increase in the quality and intensity of innovative output from national laboratories—we judged that an overreliance on the R&D 100 Awards data would make our results potentially dependent on whatever factors may have contributed over time to the change in the profile of recipients of these awards.

Another alternative measure of innovation outcomes that we explored during the project was information from databases on high-growth firms. Following the pioneering work by Birch (1979, 1987), such firms are sometimes known as gazelles. The data on the gazelles have the merit of not being derived from a process of self-nomination, and are thus relatively immune from the sort of selection bias potentially present in the R&D 100 Awards data. In contrast to the R&D 100 Awards that focus on technologies, the Fast-100 and other such databases focus on firms. The relationship between a firm's capability to create new technologies and its rate of growth is not direct. For this reason, we chose not to organize the study around the presence of gazelles as primary innovation indicator.

Research funded by ATP and performed by CHI Research provided a novel solution to the challenge of measuring innovation outcomes.

4.2. A NOVEL SOLUTION TO THE PROBLEM OF MEASURING INNOVATION OUTCOMES

As noted previously, the use of patents as a proxy for innovation outcomes involves two problems. The first is that not all innovations are patented. In many industries, the preferred form of intellectual property protection is trade secret. Process innovations may also be systematically subject to different rates of patenting than other product innovations. The 1982 SBA innovation count was an attempt to get around the shortcoming of patents as an innovation proxy. The CHI Research methodology uses patents as its starting point, and thus is still subject to the critique that it does not capture nonpatented innovations.

The second problem with the use of patents as a proxy for innovation outcomes is that patents vary greatly in their technological and economic impact. The literature contains numerous approaches to dealing with the variability of patent quality. One category of approaches focuses on characteristics of the patents themselves. The number of references to prior art, also known as backward citations, has been argued by some to be a better indication of the potential value of a patent. Refinements of this approach have measured the dispersion of citations made across patent classes. The number of claims made in the patent—the manner in which the invention is defined—provides another approach. Although these approaches have the benefit of being applicable to current patents, they are deficient, in some sense, because their self-reported quality. Furthermore, it is not clear a priori whether large numbers of backward citations or claims are indicative of a patent that is exceptionally novel, or rather of one that is exceptionally derivative and incremental.[2]

It is clear that the quality of an academic article is better measured by the number of references the article receives in the subsequent literature than it is by a simple count of the number of theorems the paper itself contains, or the number of references it cites. For that reason, a preferred indicator of patent quality is the number of times that the patent is referred to by other patents, known as forward citations. The forward citations link a patent to future inventions. Large numbers of forward citations directly indicate that a patent has had an impact.

For policy purposes, however, forward citations have a significant drawback: they take many years to accumulate. Today we can readily identify the seminal patents that enabled electronic fuel injection systems or combinatorial chemistry to occur. Those inventions are

2. See Lanjouw and Shankerman (2004), Allison et al. (2003), and references therein.

now decades old. Identifying such patents does not assist in the task of identifying emerging technology regions.

The CHI Research methodology represents one approach to addressing this shortcoming. The approach makes use of both backward and forward citations. Intuitively, the algorithm is analogous to the ones used by online booksellers to come up with titles promoted with the claim, "Buyers like you also bought these books." In this case, each purchase is like a backward citation: Buyer A reveals something about his interests by buying a certain book, just as an inventor reveals something about her interests by citing a previous patent. Furthermore, the fact that Buyer A and Buyer B both bought the same book indicates that the two have something in common; the same holds for Inventor A and Inventor B both citing the same prior patent. If it turns out that six out of seven books purchased in a given month by Buyer A were also among those purchased by Buyer B, we would have a very strong reason to believe both that: (1) Buyer A and Buyer B share interests, and (2) the books purchased by both buyers are potentially hot items.

Figures 8a and 8b illustrate the manner in which recently and frequently cited hot patents define virtual clusters of core technologies (in our analogy, the books purchased), just as the same citations reveal relationships among current patents (in our analogy, the buyers) that are in their own virtual clusters.

In more precise terms, then, the CHI Research method is in three parts:

Step 1: Select a time period. The first step is to select one or more time periods for use in the study. The CHI Research work used in this report was based on two time periods: January 1997 to August 1998, and January 2001 to August 2002. The two time periods define two distinct domains of study. The first is composed of all utility patents granted between January 1997 and August 1998. The second is composed of all utility patents granted between January 2001 and August 2002. We will refer to these two groups respectively as "the 1998 patent cohort" and "the 2002 patent cohort."

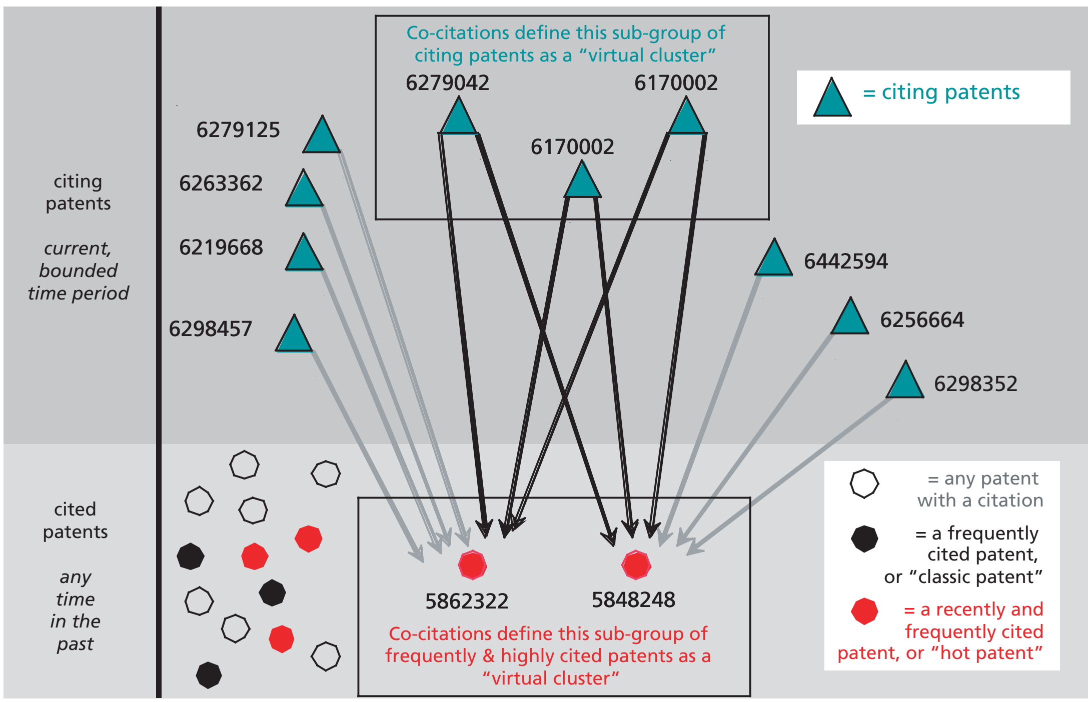
Step 2: Identify a subset of all patents that are both frequently and recently cited. The second step is to look at the citations separately for each of the two cohorts identified. Note that the citations will include patents not in the cohort. That is to say that a 1998 patent may cite a patent from 1965 or any other year before 1998. Therefore, the domain of patents cited by a given cohort contains all patents issued before the year of that cohort. For both the 1998 and 2002 patent cohorts, it turns out that fewer than 5 percent of prior patents receive a total of 10 or more total citations from patents in the cohort. The fact that a patent is *both* frequently and recently cited strongly suggests that it has had significant technological and economic impact. Just as a hot item in a store is one that is getting a lot of attention from buyers, we employ the term hot patents to refer to those patents that are frequently and recently cited.

Step 3: Identify groups of citing patents that all cite the same heavily and frequently cited hot patents. The third and most novel step in the CHI Research methodology is to identify

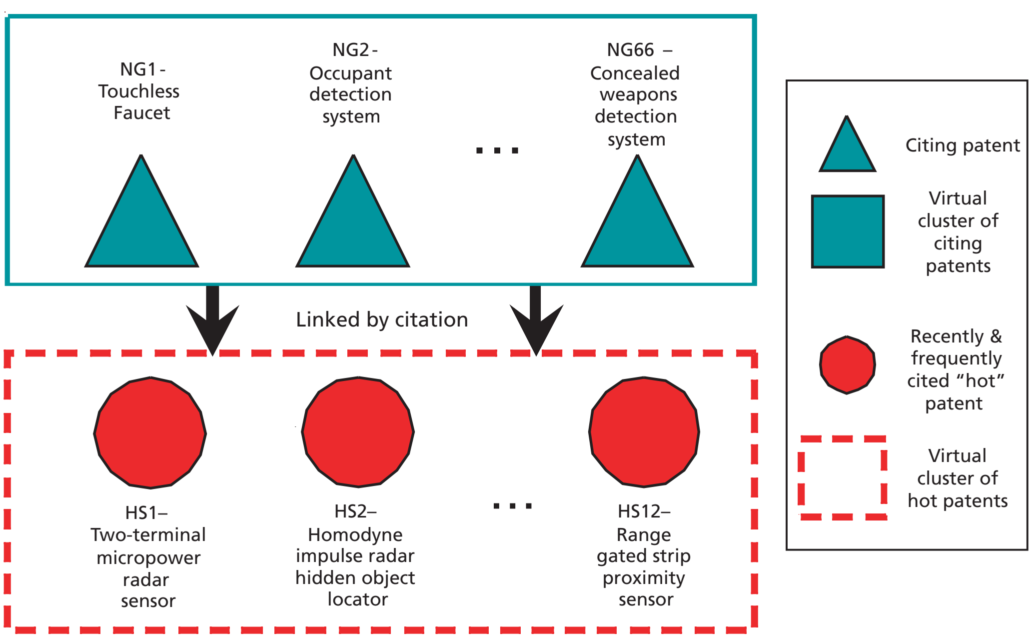
FIGURES 8A AND 8B

Co-citations Define "Virtual Clusters" of Patents, Representing Particular Emerging Core Technologies

8A



8B



subsets of patents within each cohort that cite the same heavily and frequently cited patent or patents. Although undifferentiated patents in a cohort may appear as a tangled jungle, patents in a cohort sorted using the CHI Research methodology are something much closer to a tidy orchard, in which trees present different pathways of technological discovery and are directly identifiable. A particular large tree represents an emerging technology area. We refer to the branches of such a tree as an emerging technology area. The set of all patents defining all emerging technology areas we refer to collectively as the emerging technology patents in the given cohort.

One note of caution with regard to terminology is in order: emerging technology branches identified by the CHI Research methodology are not geographically bounded. They will not necessarily define a local innovation cluster. To the contrary, one potentially interesting aspect of different technology branches is the extent to which the patents of which they are composed are geographically concentrated or dispersed. Similarly, it is interesting to explore the extent to which the patents constituting a given next-generation technology branch are located in the vicinity of the classic patents from which they collectively originate. We report below on initial investigations along both of these lines of inquiry. In this sense, the concept of an emerging technology branch contrasts both with interfirm production networks and Porter's spatially situated concept of a cluster.

Although the CHI Research method described above has distinct advantages over competing approaches, it does not by any means solve all the problems associated with the measurement of innovation. Two caveats are particularly warranted, as follows:

First, because it is based entirely on patent data, the CHI Research method does not account for the fact that some innovations are more likely to be protected by patents than others. As we have emphasized, systematic differences in this regard exist between process and product patents, between large and small firms, and among different industries. Interindustry variation in patenting propensity, in turn, may be a consequence either of systematic differences in technological fundamentals (for example, biotechnology versus software) or of the stage in industry development (for example, biotechnology versus nanotechnology).

Second, although intuition and some empirical evidence justify the approach taken in this study, the CHI Research method is not yet validated in this context. Additional work (potentially using historical data for which ultimate outcomes are known) is required to confirm that the emerging technology citing patents identified by the CHI Research methodology are, in fact, more likely than other patents to be of high value and to result in commercial innovations. Furthermore, even if additional research is consistent with the claim that the emerging technology patents identified are more likely than others to result in innovations, the question would remain whether the resultant innovations were, on the whole, integrative advancements on existing practice or derivative, incremental improvements. Which of the two turns out to be the case is clearly important for the interpretation of results.

4.3. ATTRIBUTES OF THE TOP-PERFORMING 10 PERCENT OF MSAs: MANY PATENT LAWYERS, FEW RACETRACKS

We now have defined frequently and recently cited hot patents and the emerging technology patents that cite them; we also have described why, subject to a pair of important caveats, emerging technology patents may be a more precise measure of innovation than either all patents, or subsets of patents identified as being of high quality using the alternative approaches discussed.

To use these patent counts to identify technological emergence, we emphasize the temporal dimension: hot patents represent a previous generation of invention leading to innovation; current patents are the new generation. To highlight the shifts that have taken place in one short technological generation (5–10 years) in terms of the geographical dispersion of innovative activity, we compare the top 10 percent of MSAs ranked in terms of number of inventors of hot patents and emerging technology patents, respectively (Table 1). The hot patents represent inventions from the mid-1990s (roughly) that were having an impact in 2002; the emerging technology patents identify inventors in the 2002 patent cohort who are working on the hot ideas of the moment, as indicated by the interests of peers.

A 100 percent overlap exists between the two lists of leading technology regions as defined by the frequently and recently cited hot patents, and by the next generation emerging technology patents. Every MSA present in the list of the top 10 percent in terms of citing patents is also present in the list of the top 10 percent of MSAs in terms of emerging technology patents. Of the 32 MSAs in question, 8 rank higher in the list of citing patents (corresponding to 2002 activity) than they did in the list of cited patents (corresponding to activity in the mid-1999s): Boise, Idaho (+4); Houston, Texas (+4); Portland-Vancouver, Oregon-Washington (+2); Atlanta, Georgia (+2); Monmouth-Ocean, New Jersey (+2); Pittsburgh, Pennsylvania (+2); Austin-San Marcos, Texas (+1); and Seattle-Bellevue-Everett, Washington (+1). These MSAs are distributed throughout the country, with the two that made the most progress located far from the East and West coasts.

To take this analysis one step further, we return to the full set of variables introduced earlier to compare the concentration of various types of entities in the top performing regions.

As a baseline, we determined that 44 percent of the U.S. population was accounted for by the top 10 percent most innovative MSAs in the mid-1990s. Thus, MSAs performing in the top 10 percent in terms of innovative output are considerably more populous that the average MSA in the United States. If, collectively, these regions were to account for exactly 44 percent of all patents, there would be little left to explain: more people led to more ideas. As Table 2 indicates, however, the top 10 percent of performing regions accounted for fully 74 percent of all emerging technology patents—1.7 times their share if population were the only determinant.

TABLE 1

Comparison of Leading Technology Regions in the Mid-1990s and in 2002

Rank	**Leading U.S. Technology Regions in the Early 1990s** *MSAs with the most inventors of frequently and recently cited hot patents (2002 cohort)*	**Leading U.S. Technology Regions in 2002** *MSAs with the most inventors of emerging technology patents (2002 cohort)*	**Movement in the Rankings**
1	San Jose CA	San Jose CA	—
2	Boston MA-NH	Boston MA-NH	—
3	San Francisco CA	San Francisco CA	—
4	New York NY	New York NY	—
5	Oakland CA	Boise City ID	+4
6	San Diego CA	Oakland CA	–1
7	Minneapolis-St. Paul MN-WI	San Diego CA	–1
8	Chicago IL	Chicago IL	—
9	Boise City ID	Minneapolis-St. Paul MN-WI	–2
10	Los Angeles-Long Beach CA	Austin-San Marcos TX	+1
11	Austin-San Marcos TX	Los Angeles-Long Beach CA	–1
12	Dallas TX	Seattle-Bellevue-Everett WA	+1
13	Seattle-Bellevue-Everett WA	Houston TX	+4
14	Washington DC-MD-VA-WV	Dallas TX	–2
15	Detroit MI	Washington DC-MD-VA-WV	–1
16	Rochester NY	Detroit MI	–1
17	Houston TX	Rochester NY	–1
18	Orange County CA	Portland-Vancouver OR-WA	+2
19	Philadelphia PA-NJ	Orange County CA	–1
20	Portland-Vancouver OR-WA	Philadelphia PA-NJ	–1
21	Newark NJ	Newark NJ	—
22	Bridgeport CT	Bridgeport CT	—
23	Middlesex-Somerset-Hunterdon NJ	Atlanta GA	+2
24	Phoenix-Mesa AZ	Middlesex-Somerset-Hunterdon NJ	–1
25	Atlanta GA	Monmouth-Ocean NJ	+2
26	Raleigh-Durham-Chapel Hill NC	Phoenix-Mesa AZ	–2
27	Monmouth-Ocean NJ	Pittsburgh PA	+2
28	Baltimore MD	Raleigh-Durham-Chapel Hill NC	–2
29	Pittsburgh PA	Baltimore MD	–1
30	Boulder-Longmont CO	Boulder-Longmont CO	—
31	Dutchess County NY	Dutchess County NY	—
32	Nassau-Suffolk NY	Nassau-Suffolk NY	—

TABLE 2

Percent of Key Variables Accounted for by Top Technology Regions (2002 Cohort)

Variable	Percent accounted for by top 10% most innovative MSAs (2002 cohort)	Percent divergence from baseline
Innovation Infrastructure: Venture capital recipient companies	86	42
Innovation Infrastructure: Venture capital firms	80	36
Emerging technology patents (2002 cohort)	74	30
Innovation Infrastructure: Patent lawyers	74	30
Innovation Infrastructure: Hot patents	73	29
Policy Variable: ATP awards	61	17
Creativity and culture—professional: Management Consulting	58	14
Creativity and culture—art and performance: Live theater	57	13
Creativity and culture—professional: Management services	56	12
Innovation Infrastructure: IT-software companies	55	11
Creativity and culture—professional: Architectural services	52	8
Policy Variable: SBIR Phase I awardees	50	6
Creativity and culture—art and performance: Live-band-orchestras	50	6
Innovation Infrastructure: Physical-research	49	5
Policy Variable: SBIR Phase II Awardees	48	4
Innovation Infrastructure: Engineering services	48	4
Social capital: Business associations	46	2
Innovation Infrastructure: Testing labs	46	2
Policy Variable: Incubators	46	2
Creativity and culture—reading, crafts: Bookstores	46	2
Population 2002	**44**	**0**
Innovation Infrastructure: University R&D funding	44	0
Innovation Infrastructure: University-colleges with more than 1,000 employees	42	–2
Creativity and culture—reading crafts: Hobby shops	41	–3
Social Capital: Civic and social associations	38	–6
Creativity and culture—art and performance: Museum & art galleries	38	–6
Creativity and culture—religion: Religious organizations	35	–9
Social Capital: Bowling centers	34	–10
Creativity and culture—disamenity: Racetracks	27	–17
Creativity and culture—disamenity: Correctional facility	25	–19

The share of population accounted for by the 10 percent most innovative MSAs in the mid-1990s (as measured in terms of numbers of cited patents) helps put the results pertaining to other variables into context. As reported in Table 2, regions that are disproportionately strong in generating core technology patents are also home to more than their share of patent lawyers, management consulting firms, theaters featuring live performances, information technology companies, and recipients of awards from ATP.

The strongest technology regions have only slightly more than their share of SBIR Phase I and Phase II awardees, suggesting that these awards (lower in amount than the ATP awards) go to firms somewhat more widely distributed throughout the country than the ATP awards. Less surprisingly, incubators are also relatively evenly distributed. Like colleges and universities, bookstores, business associations, and K-12 schools, incubators are distributed roughly in proportion to the distribution of the population.

On a per capita basis, the most innovative regions are home to fewer religious organizations and bowling centers than other regions; in each category, the top 10 percent of hot patent MSAs have 23 percent fewer institutions than would be the case if population were the only determinant. The suggestion of a negative correlation with innovative capacity is even stronger when it comes to one particular entertainment category: If technology entrepreneurs want to see a NASCAR race, it is likely they will have to travel, as the leading technology regions account for 40 percent less than their population-weighted share of racetracks. (It should be noted that just because this correlation exists, does not mean there is a causal relationship. For instance, shutting down racetracks does not mean that innovation will be enhanced in a region.)

For institutions whose presence is negatively correlated to high performance in science-based innovation, the most robust result pertains to correctional facilities. Although encompassing 44 percent share of the population, the leading hot patents MSAs account for only 25 percent of correctional facilities in the sample.

4.4. DISTRIBUTION OF CREATIVE AND TECHNOLOGICALLY INTENSIVE ACTIVITIES WITHIN MSAs

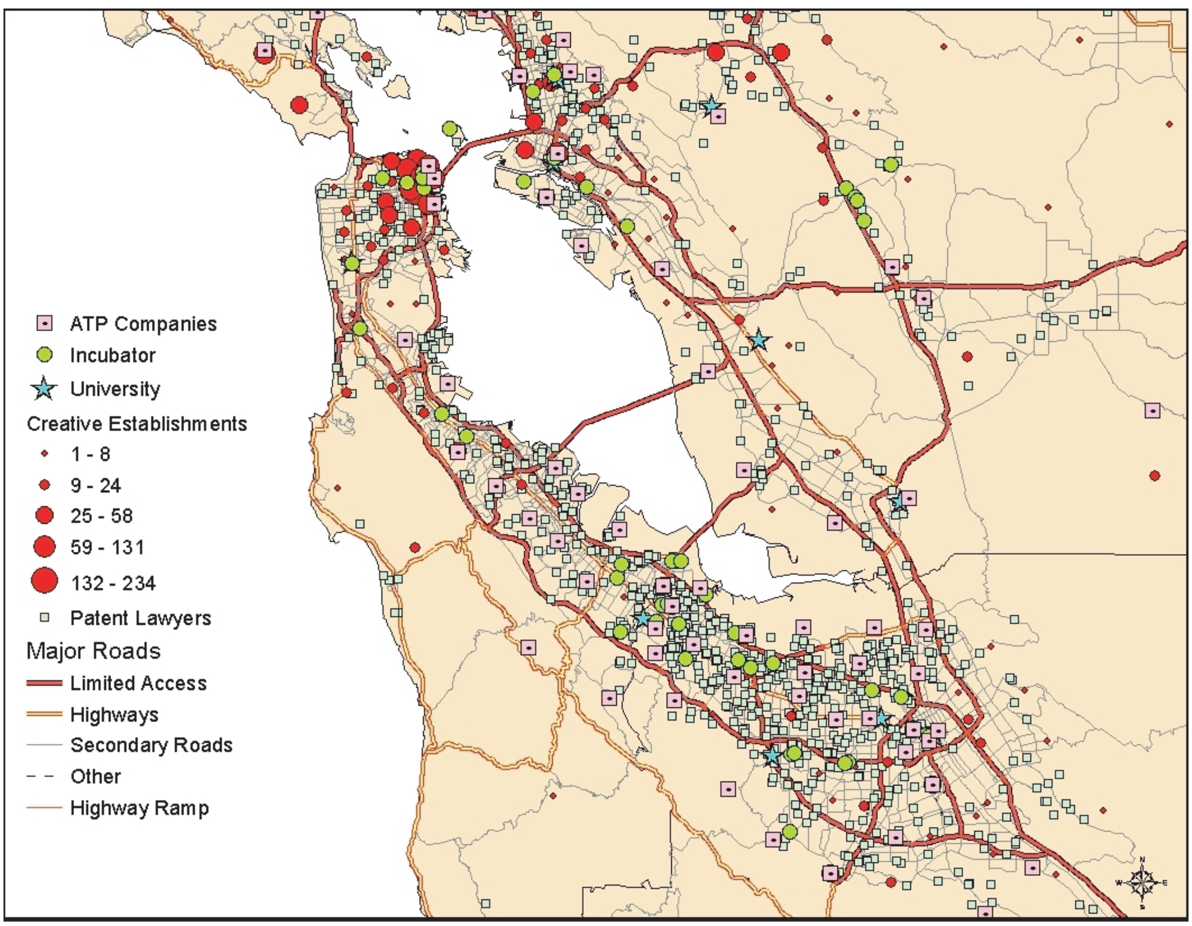
Our analysis of spatial distributions has so far focused entirely on the MSA as the unit of analysis. This is consistent with most work on regional innovation. The power of GIS methodology, however, is that it can be used to explore the same data at different levels of aggregation.

The role of creative professionals in driving technology development is a case in point. Florida (2002a, 2002b) has reported a close correspondence at the MSA scale between the presence of creative professionals and regional economic performance. There has been little study of the manner in which creative professionals are geographically distributed, however, within metropolitan areas. Figures 9 through 13 display maps of five metropolitan areas: San Francisco, California; Boston, Massachusetts; Austin, Texas; Chicago, Illinois; and Nashville, Tennessee. The first four of these are leading technology MSAs; Nashville is not. Each map displays concentrations at the zip code level of universities, incubators, patent lawyers, recipients of SBIR awards, recipients of ATP awards, and bands and orchestras (SIC code 7929).

The San Francisco map (Figure 9) evidences the region's wealth of institutions involved in technology-based innovation and creative professions. Although the offices of patent lawyers are found everywhere, ATP recipient companies are heavily concentrated in Silicon Valley (the southern part of the region shown), while bands and orchestras are concentrated in the downtown areas of the city of San Francisco. It is important to note that these are establishment data; we do not have data on the residences of the people who work in the enterprises mapped. The maps do make clear that some categories of creative and

FIGURE 9

San Francisco Bay Area, by Zip Code: ATP Award-Recipient Firms, SBIR Award-Recipient Firms, Universities, Intensity of Patent Lawyers, and Number of Bands and Orchestras

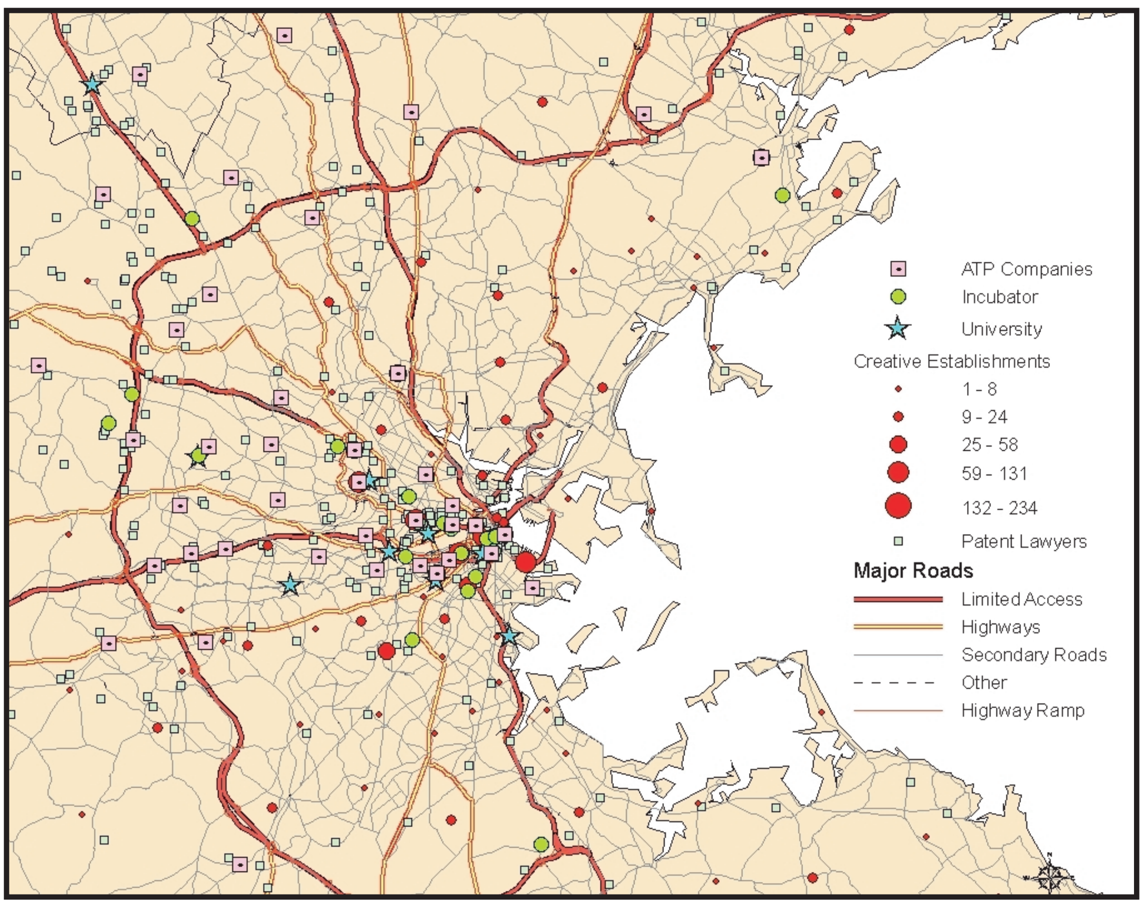


Note: SIC code 7929—Bands, Orchestras, Actors and Other Entertainers and Entertainment Groups—are labeled "creative establishments" on map.

technologically intensive enterprises may jointly be present in the same high-output MSAs; within the MSA they may be dispersed. The maps of Boston, Austin, and Chicago (Figures 10 through 12) indicate that in these regions technology-based innovation and creative activities generally appear to be collocated. The map of Nashville (Figure 13), which ranks 78th out of the 318 MSAs in terms of hot patents, contrasts sharply with the maps of the other four regions. Although the city's count of live bands and orchestras compares favorably with that of Austin (both being cities renowned for their music scenes) and it is home to 42 universities and colleges, it has only one ATP award-recipient firm and just a handful of patent lawyers (who are elsewhere highly correlated with regional innovative output).

FIGURE 10

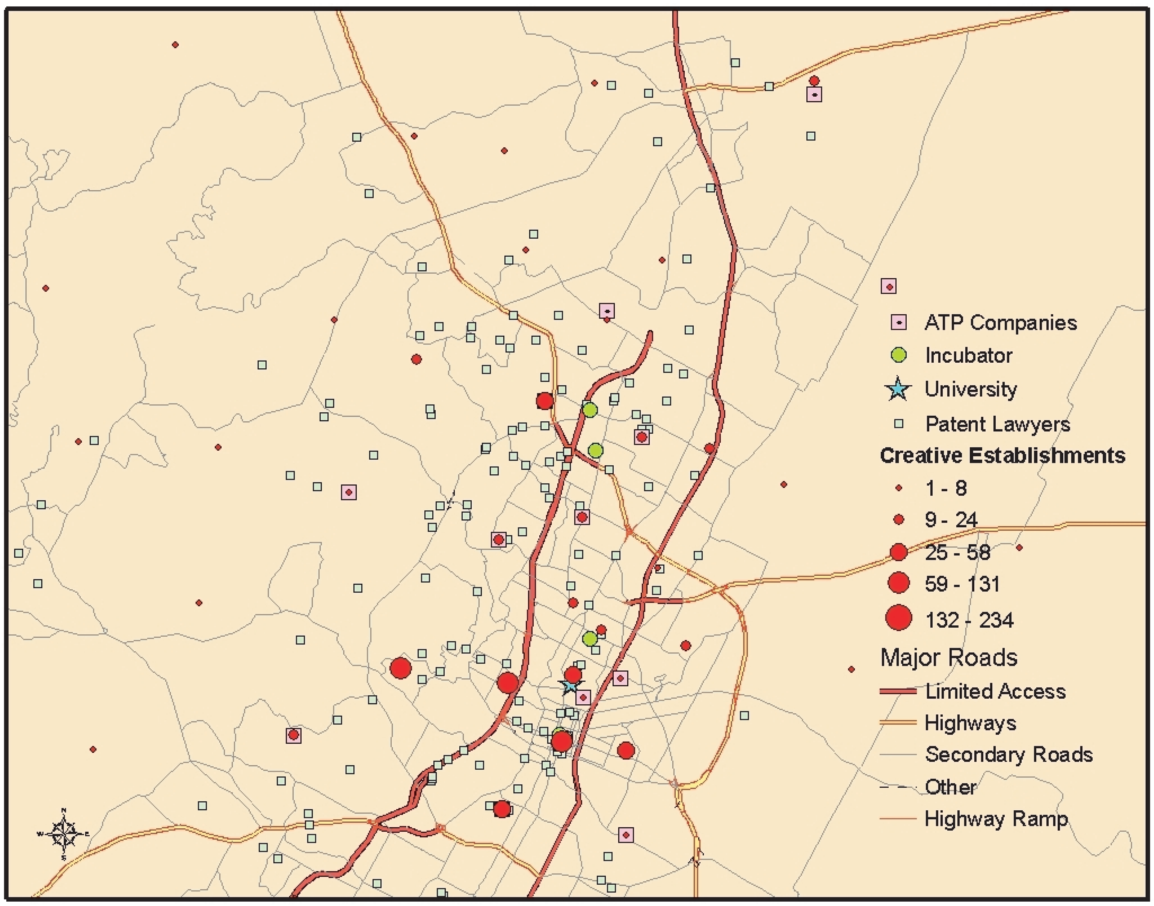
Boston (MA) Metro Area, by Zip Code: ATP Award-Recipient Firms, SBIR Award-Recipient Firms, Universities, Intensity of Patent Lawyers, and Number of Bands and Orchestras



Note: SIC code 7929—Bands, Orchestras, Actors and Other Entertainers and Entertainment Groups—are labeled "creative establishments" on map.

FIGURE 11

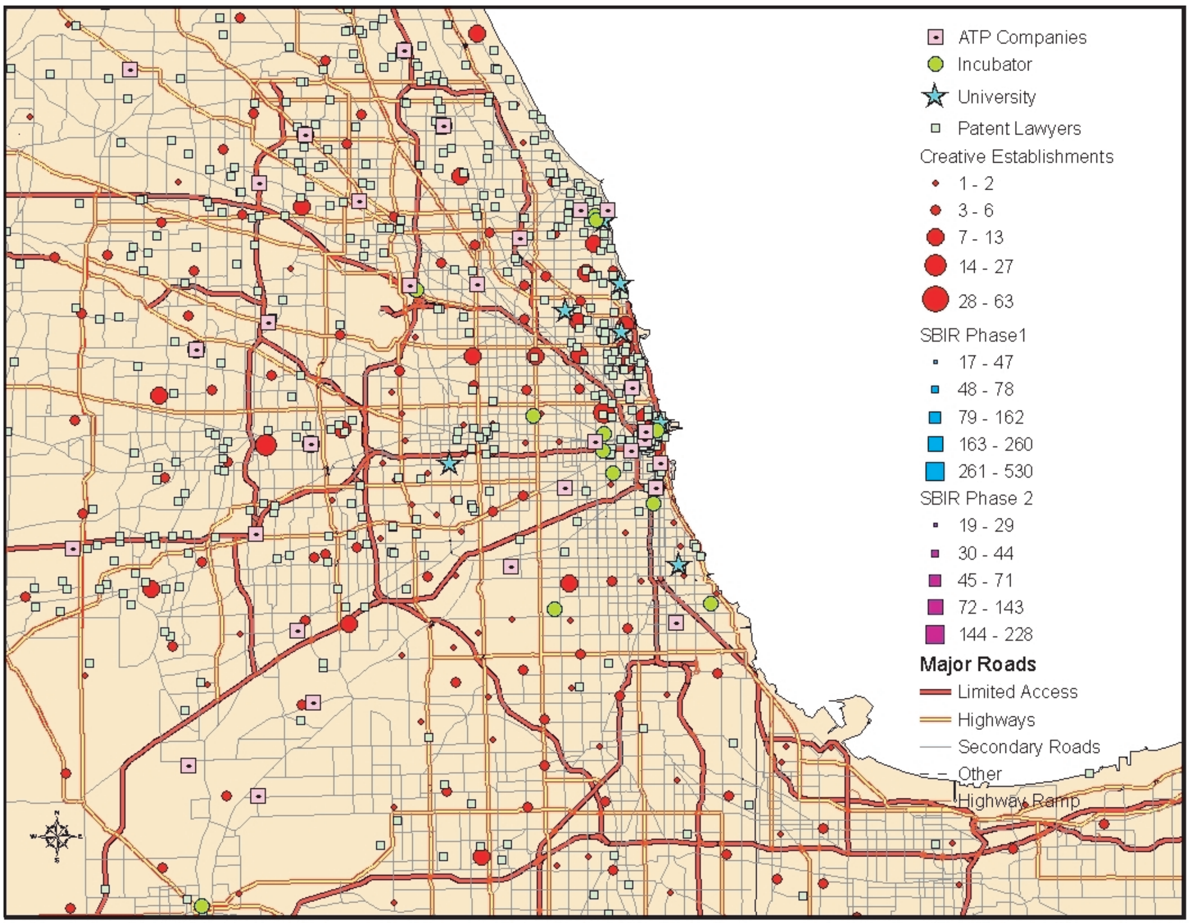
Austin (TX) Area, by Zip Code: ATP Award-Recipient Firms, SBIR Award-Recipient Firms, Universities, Intensity of Patent Lawyers, and Number of Bands and Orchestras



Note: SIC code 7929—Bands, Orchestras, Actors and Other Entertainers and Entertainment Groups—are labeled "creative establishments" on map.

FIGURE 12

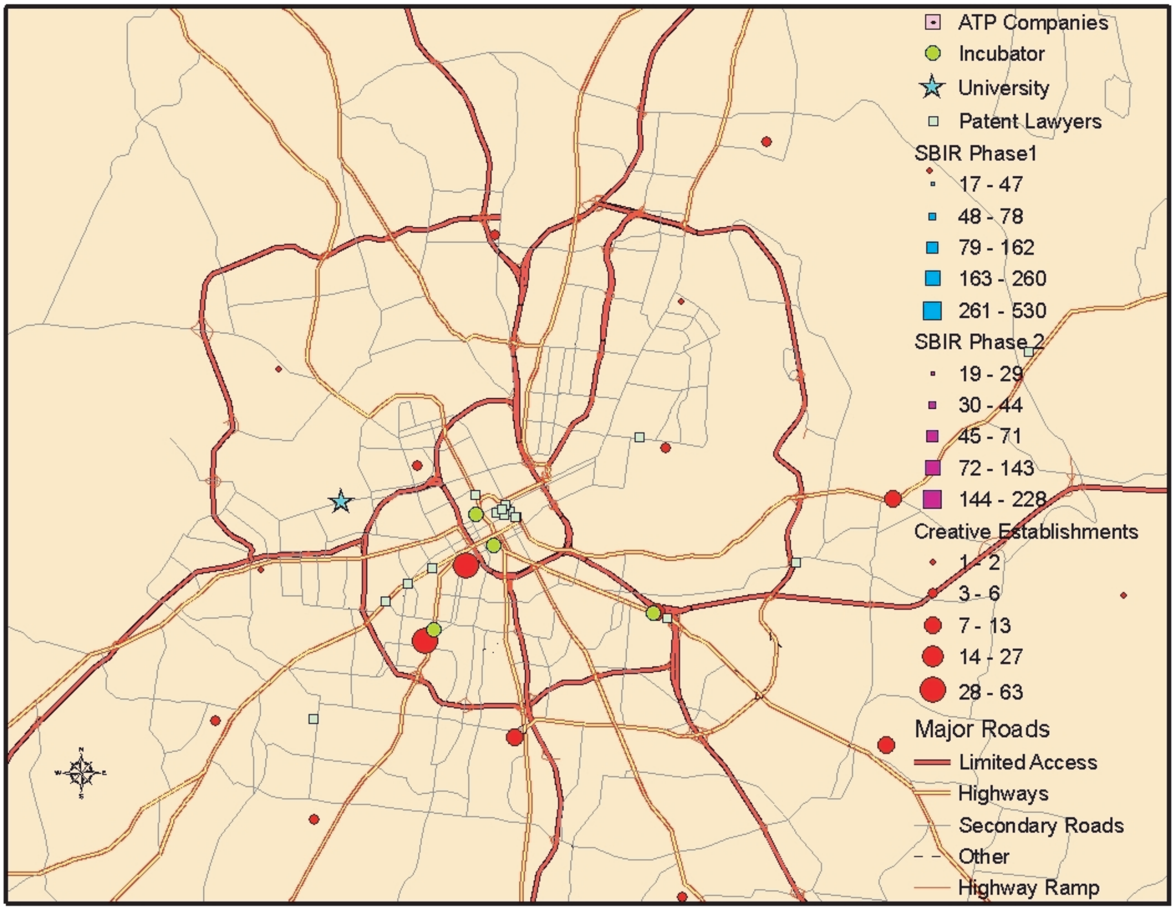
Greater Chicago (IL) Metro Area, by Zip Code: ATP Award-Recipient Firms, SBIR Award-Recipient Firms, Universities, Intensity of Patent Lawyers, and Number of Bands and Orchestras



Note: SIC code 7929—Bands, Orchestras, Actors and Other Entertainers and Entertainment Groups—are labeled "creative establishments" on map.

FIGURE 13

Nashville (TN) Area, by Zip Code: ATP Award-Recipient Firms, SBIR Award-Recipient Firms, Universities, Intensity of Patent Lawyers, and Number of Bands and Orchestras



Note: SIC code 7929—Bands, Orchestras, Actors and Other Entertainers and Entertainment Groups—are labeled "creative establishments" on map.

Considered together, Figures 9 through 13 illustrate the manner in which GIS technology permits research at different levels of geographical resolution, depending on the question being considered. Correlations with possible causal factors can change significantly at different scales of analysis. A further indication of the way in which scale of analysis matters is shown in Table 3, which displays the spatial concentration of SBIR Phase I award-recipient companies and patent lawyers at three different levels of aggregation: zip code, county, and MSA. The result is intuitively obvious: variations within state get smoothed out in the higher levels of aggregation. The differences are still worth noting. Among zip codes, only 14 percent are home to at least one SBIR Phase I award recipient company; at the scale of the MSA, the fraction is 85 percent.

TABLE 3

Spatial Concentration of SBIR Phase I Award-Recipient Companies and Patent Lawyers at Three Different Levels of Aggregation: Zip Code, Country, and MSA

SBIR Phase I Awards	
14% of zip codes have SBIR Phase I award-recipient companies	
	231 zip code areas account for 50% of awards
Zip codes	435 zip code areas account for 63% of awards
	12 zip codes account for 10% of awards
26% of counties (833 of 3,141) have SBIR Phase I award-recipient companies	
	24 counties account for 50% of awards
Counties	44 counties account for 63% of awards
	One county (Middlesex, MA) accounts for nearly 10% (9.2%) of awards
85% of MSAs (288 of 337) have SBIR Phase I award-recipient companies	
	14 MSAs account for 50% of awards
MSAs	25 MSAs account for 63% of awards
	One MSA (Boston NEMSA) accounts for 10% of awards
Patent Lawyers	
16.21% of zip codes (4,887 out of 30,143) have patent lawyers	
	197 zip code areas account for 50% of patent lawyers
Zip codes	444 zip code areas account for 63% of patent lawyers
	9 zip code areas account for 10% of patent lawyers
31.23% of counties (981 counties of 3,141) have patent lawyers	
	22 counties account for 50% of patent lawyers
Counties	38 counties account for 63% of patent lawyers
	Two jurisdictions (Washington, D.C., and New York) account for 10% of patent lawyers
83.38% of MSAs (281 out of 337) have patent lawyers	
	11 MSAs account for 50% of patent lawyers
MSAs	20 MSAs account for 63% of patent lawyers
	One MSA (Washington, D.C. MSA) accounts for 10% of patent lawyers

Note: NEMSA = New England Metropolitan Statistical Area.

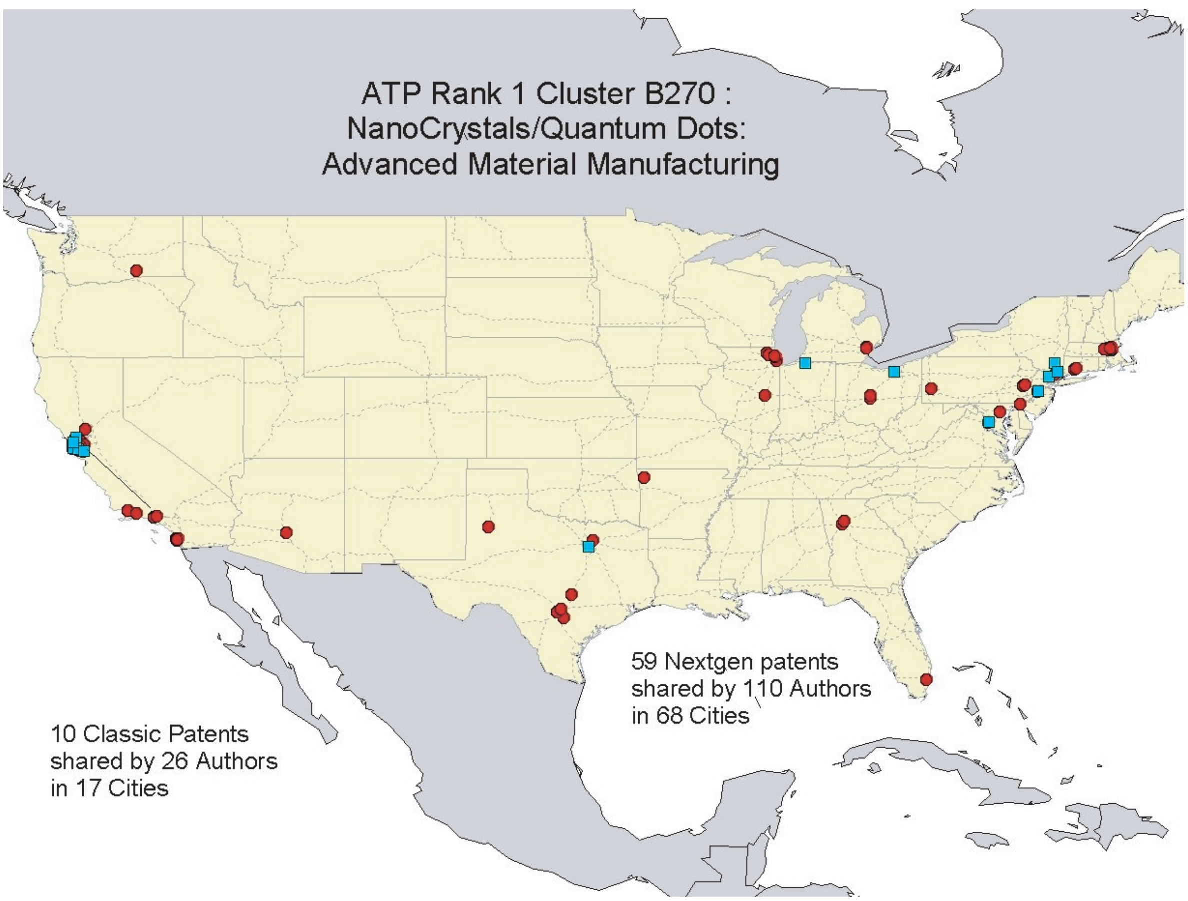
4.5. EMERGING TECHNOLOGY REGIONS

This subsection presents the report's core findings: maps and characteristics of emergent technology regions in the United States. The method used is as simple and direct as its motivation. We have argued in the foregoing that hot patents and emerging technology patents are indicators pertaining to two different generations in the development of core technologies. This point is made more clearly in Figures 14 through 18, which plot hot patents and subsequent emerging technology patents for five technology areas prominent in the 2002 patent cohort: advanced materials manufacturing—nano crystals/quantum dots (Figure 14); advanced manufacturing—lycocell fibers and liquid moving fibers (Figure 15); cell biology, immunology, molecular biology, pharmaceutical (Figure 16); microfluidic and miniaturized systems manufacturing (Figure 17); and polymers, plastic, and manufacturing (Figure 18).

FIGURE 14

Locations of Frequently and Recently Cited "Hot Patents" (Green Square) and the "Emerging Technology Patents" (Red Dot) in a Core Technology Space

Advanced materials manufacturing—nano crystals/quantum dots (CHI technology category no. B270)



It is clear from these maps that technologies migrate. The 26 inventors responsible for the 10 frequently and recently cited hot patents in nano crystals/quantum dots, for example, are concentrated in the four top technology MSAs: San Jose, California (Silicon Valley); San Francisco, California; Boston, Massachusetts; and New York, New York. The further development of these technologies has taken place in diverse MSAs—from Washington State to the bottom of the Florida peninsula. Patents for the lycocell fibers and liquid moving fibers (core technologies in diapers, among other products) have similarly migrated from a pair of Midwest MSAs to a variety of locations, none of which are in the top 10 percent of hot patent MSAs (Figure 15). In contrast, the cell biology, immunology, and molecular biology core technology area (Figure 16) and the microfluidic and miniaturized systems manufacturing core technology area (Figure 17) both show a concentration of inventive activity in a few of the top 10 technology MSAs for both generations of technology development.

FIGURE 15

Locations of Frequently and Recently Cited "Hot Patents" (Green Square) and the "Emerging Technology Patents" (Red Dot) in a Core Technology Space

Advanced manufacturing—lycocell fibers and liquid moving fibers (CHI technology category no. B392)

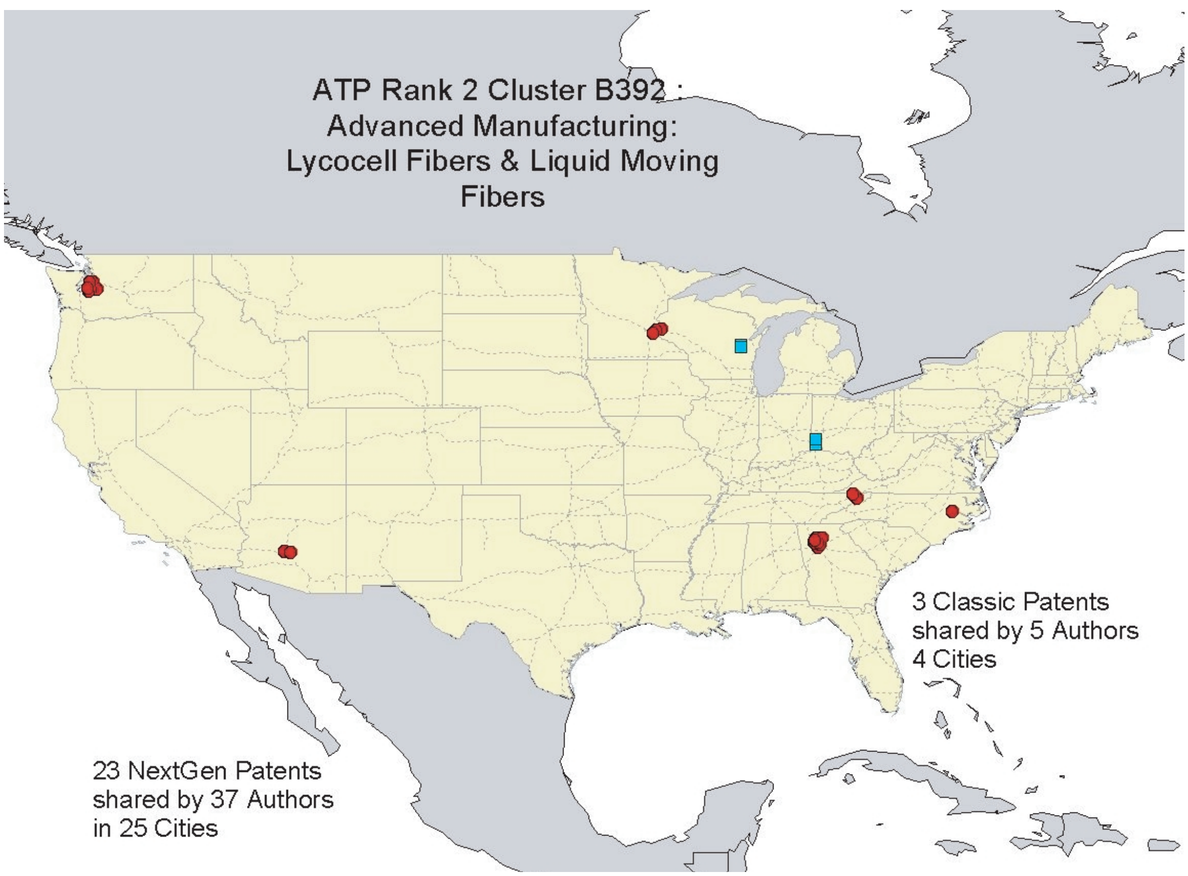


FIGURE 16

Locations of Frequently and Recently Cited "Hot Patents" (Green Square) and the "Emerging Technology Patents" (Red Dot) in a Core Technology Space

Intersection of cell biology, immunology, and molecular biology (biotechnology subcategory, CHI technology category no. B544)

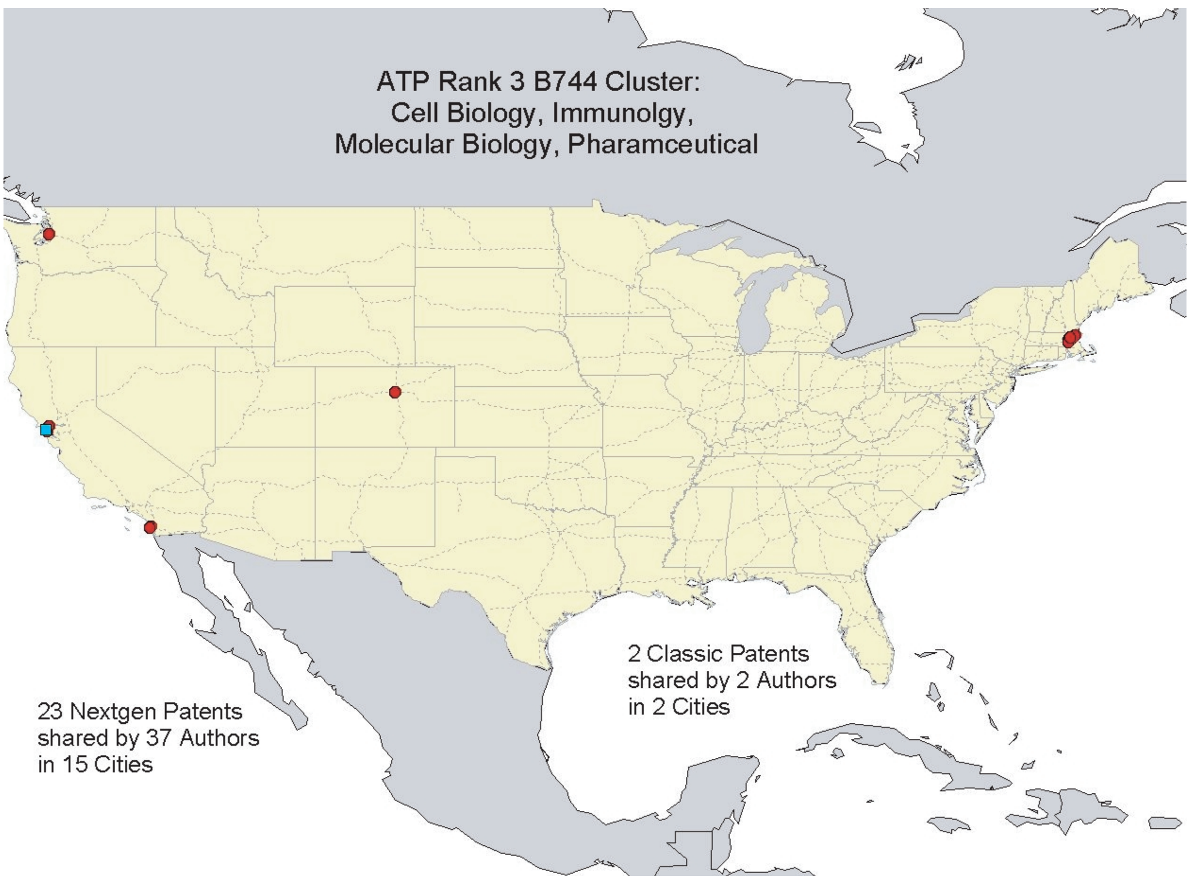


FIGURE 17

Locations of Frequently and Recently Cited "Hot Patents" (Green Square) and the "Emerging Technology Patents" (Red Dot) in a Core Technology Space

Microfluidic and miniaturized systems manufacturing (CHI technology category no. B631)

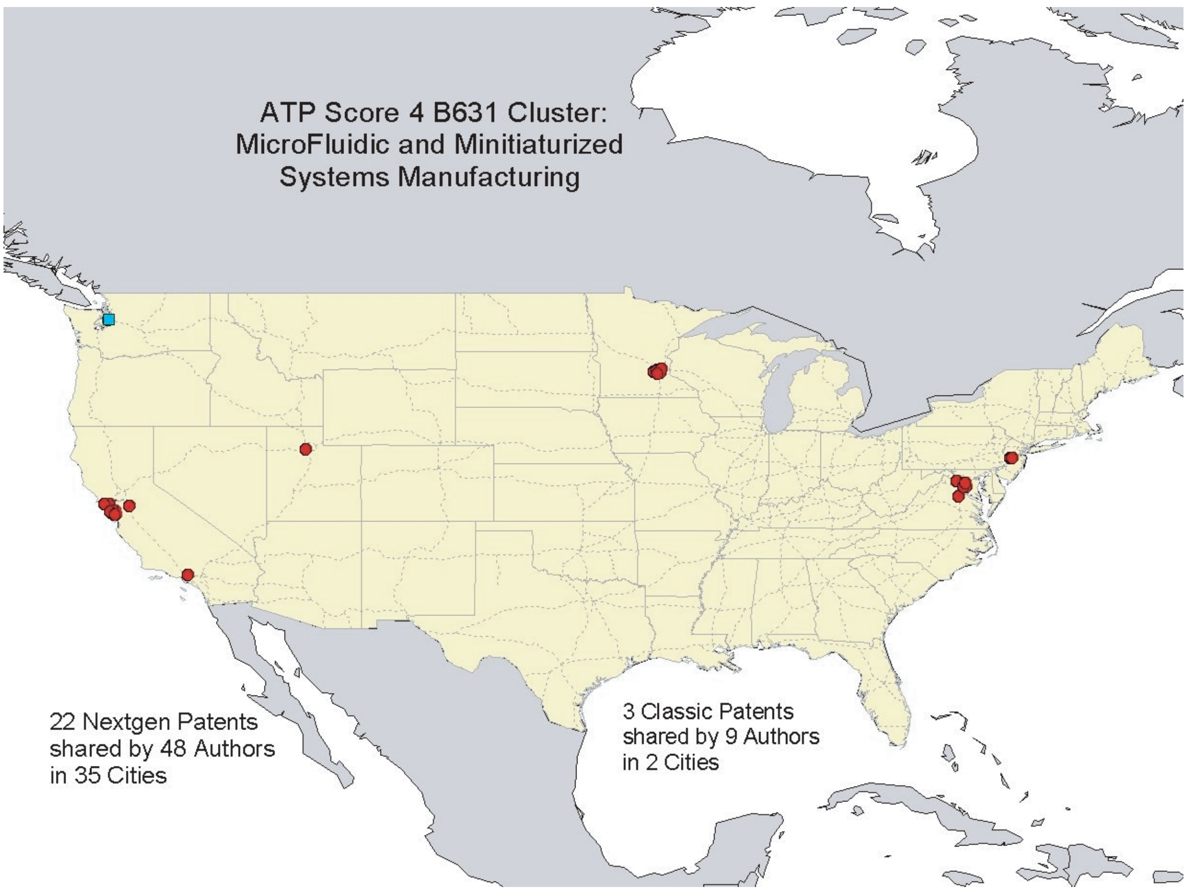
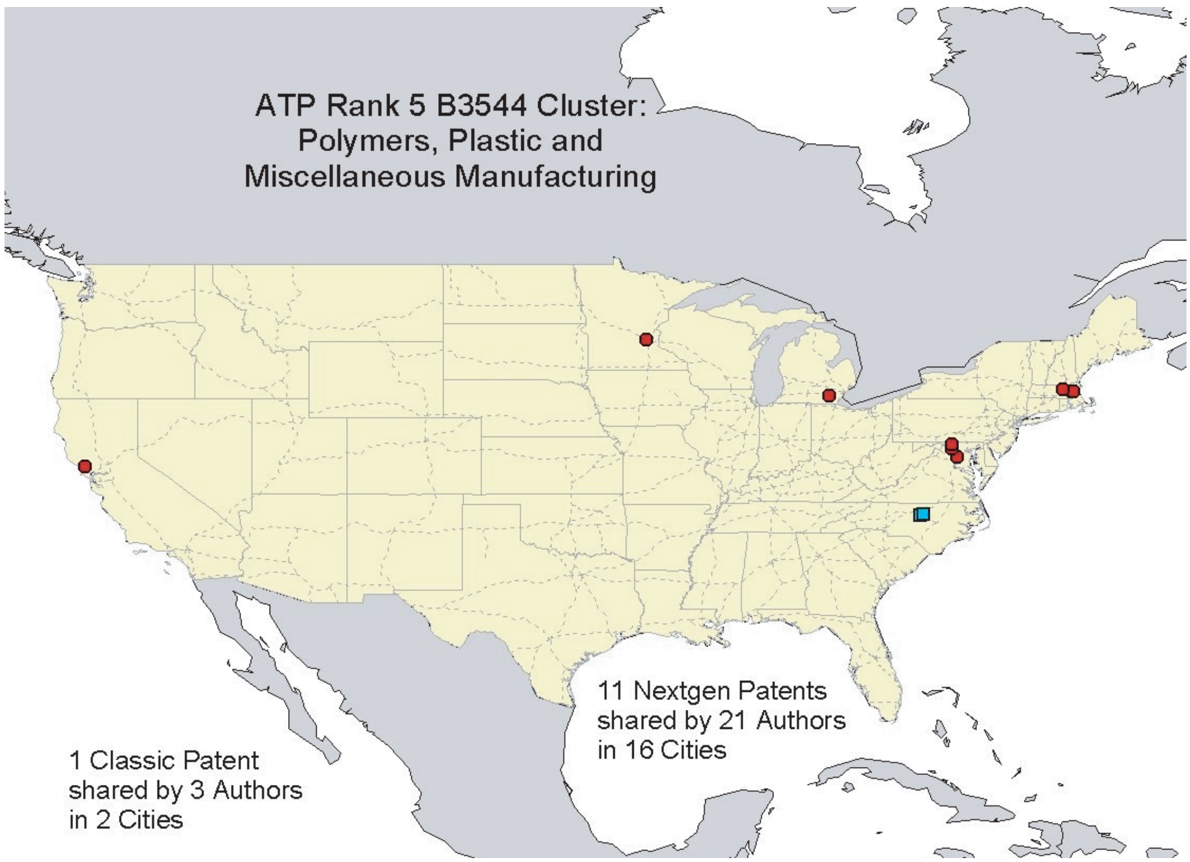


FIGURE 18

Locations of Frequently and Recently Cited "Hot Patents" (Green Square) and the "Emerging Technology Patents" (Red Dot) in a Core Technology Space

Polymers, plastic, and manufacturing (CHI technology category no. B744)



Finally, in the case of polymers, plastics, and manufacturing, a single hot patent originating from the Research Triangle area in North Carolina has been cited by emerging technology patents in the Washington, D.C. metro area, Boston, Chicago, Minneapolis, and the San Francisco Bay area.

Given the dynamic of technology development illustrated by Figures 14 through 18, the relationship between cited patents and citing patents seems to provide an indication of emerging technology activity. In particular, a simple ratio of citing patents to cited patents provides a measure of the extent to which a region contains people capable of deriving new inventions (possibly integrative, possibly derivative) from past inventions.[3] This ratio is the

3. An obvious alternative is the difference between the number of emerging technology patents and the number of hot patents. This indicator is highly sensitive to the scale of the overall regional innovation system. For this reason, it tends to rank large MSAs systematically above small ones. Calculating the difference in terms per capita output is a slight improvement, but at the cost of reduced simplicity. The ratio was chosen because it captured the desired phenomenon most directly.

measure we use as a first approximation for emergent technological capability. The cited patents used are the ones we have so far referred to as frequently and recently cited hot patents; the citing patents used are the ones we have so far referred to as emerging technology patents.

Rank ordering MSAs in terms of a citing-to-cited patent ratio yields a list of top performers very different from a ranking based on numbers of hot patents. We will refer to the top 10 percent of MSAs in terms of a citing-to-cited patent ratio as the emerging technology regions. These emerging technology regions are listed in Table 4; their characteristics are summarized in Table 5. The indicators are the same as those used in Table 2 to characterize leading technology regions (the shading of the variables used in that table to identify apparent positive correlates [dark blue] and negative correlates [light blue] of leading technology status). These Table 2 indicators are carried over into Table 5.

The first observation to make is that, where leading technology regions (Table 1) are substantially larger than average, emerging technology regions are smaller: the average population of leading technology regions is 3,275,179; of emerging technology regions, 569,632; and of all MSAs, 731,062.

The second observation is that the emerging technology regions are distributed far more evenly across the country than are the leading technology regions. This difference is evident in Figures 19 through 21: Figures 19 and 20 display concentrations of hot patents and emerging technology patents; Figure 21 displays citing-to-cited patent ratios, indicating emerging technology regions.

FIGURE 19

Inventors of Frequently and Recently Cited "Hot Patents" (Defined by 2002 Patent Cohort), Concentrations by Cities

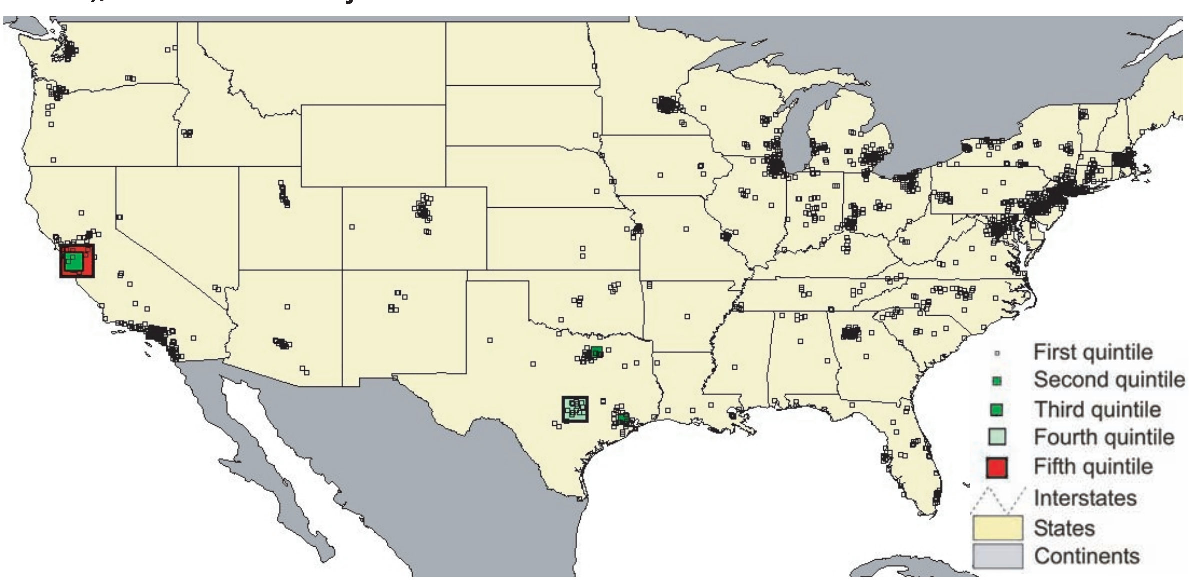


TABLE 4

Emerging Technology Regions

Emerging Technology MSA (high ratio of next generation patents to hot patents)	Population	Hot Patent Ranking	Incubators	Universities and Colleges
Longview-Marshall TX	213,608	185	1	17
Racine WI	192,284	150	1	9
Huntington-Ashland WV-KY-OH	313,661	119	2	10
Kenosha WI	156,209	186	0	5
Flint MI	442,250	214	1	11
Amarillo TX	224,668	187	1	8
Columbus OH	1,597,271	46	6	46
Gary IN	640,009	151	0	9
Utica-Rome NY	298,077	174	1	9
Santa Fe NM	155,225	80	3	9
Sioux City IA-NE	123,712	163	1	3
Lincoln NE	260,995	175	1	11
Rapid City SD	453,540	188	2	19
Jackson MS	476,751	189	0	29
Des Moines IA	91,881	215	0	11
Benton Harbor MI	162,766	143	2	11
Athens GA	158,853	152	3	6
Champaign-Urbana IL	186,800	153	2	5
Dothan AL	140,707	216	1	8
West Palm Beach-Boca Raton FL	1,216,282	50	4	25
Houston TX	4,496,835	17	10	114
Sherman-Denison TX	115,153	190	0	4
Milwaukee-Waukesha WI	1,514,313	53	9	93
Pittsburgh PA	2,338,671	28	10	57
Reading PA	385,307	123	0	5
Johnstown PA	228,818	191	1	9
Boise City ID	476,659	9	2	16
Iowa City IA	115,548	91	1	7
Lake Charles LA	183,889	105	0	8
Yuma AZ	171,134	106	0	8
El Paso TX	705,436	217	0	17
Gainesville FL	223,578	144	2	5
Fayetteville NC	303,953	192	1	22

TABLE 5

Percent of Key Variables Accounted for by Emerging Technology Regions (2002 Cohort)

Variable	Percent accounted for by emerging technology regions (2002 cohort)	Divergence from baseline
Emerging technology patents (2002 cohort)	16.9	6.9
Innovation Infrastructure: Hot patents	13.2	3.2
Policy Variable: Incubators	12.8	2.8
Innovation Infrastructure: University-colleges with more than 1,000 employees	12.5	2.5
Social Capital: Civic and social associations	11.9	1.9
Innovation Infrastructure: Testing labs	11.7	1.7
Social Capital: Bowling centers	11.4	1.4
Social Capital: Business associations	11.0	1.0
Creativity and culture—professional: Architectural services	10.7	0.7
Creativity and culture—religion: Religious organizations	10.6	0.6
Creativity and culture—art and performance: Museums and art galleries	10.4	0.4
Creativity and culture—disamenity: Racetracks (auto)	10.3	0.3
Creativity and culture—reading, crafts: Hobby shops	10.3	0.3
Innovation Infrastructure: Physical-research	10.3	0.3
Creativity and culture—art and performance: Live-band/orchestras	10.3	0.3
Creativity and culture—disamenity: Correctional facility	10.3	0.3
Creativity and culture—reading, crafts: Bookstores	10.1	0.1
Innovation Infrastructure: University R&D funding	10.1	0.1
Innovation Infrastructure: Engineering services	10.0	0.0
Creativity and culture—professional: Management consulting	9.8	–0.2
Innovation Infrastructure: IT-software companies	9.5	–0.5
Creativity and culture—professional: Management services	9.4	–0.6
Creativity and culture—art and performance: Live theater	9.2	–0.8
Policy Variable: ATP awards	8.9	–1.1
Innovation Infrastructure: Patent lawyers	8.4	–1.6
Population 2002	**8.1**	**–1.9**
Policy Variable: SBIR Phase I awardees	5.4	–4.6
Policy Variable: SBIR Phase II awardees	4.1	–5.9
Innovation Infrastructure: Venture capital firms	3.2	–4.9
Innovation Infrastructure: Venture capital recipient companies	1.8	–6.3

FIGURE 20

Inventors of Citing Patents (Defined by 2002 Cohort), Concentrations by Cities

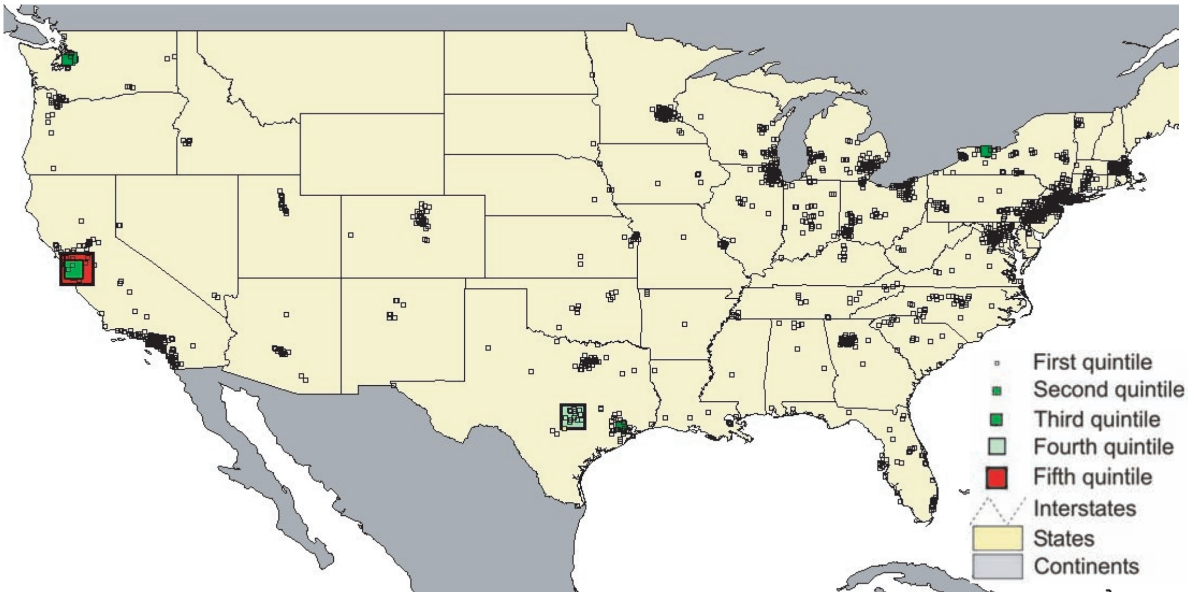


FIGURE 21

Emerging Technology Regions, Identified by the Ratio of Citing-to-Cited Patents (Both Defined by 2002 Cohort), by Cities

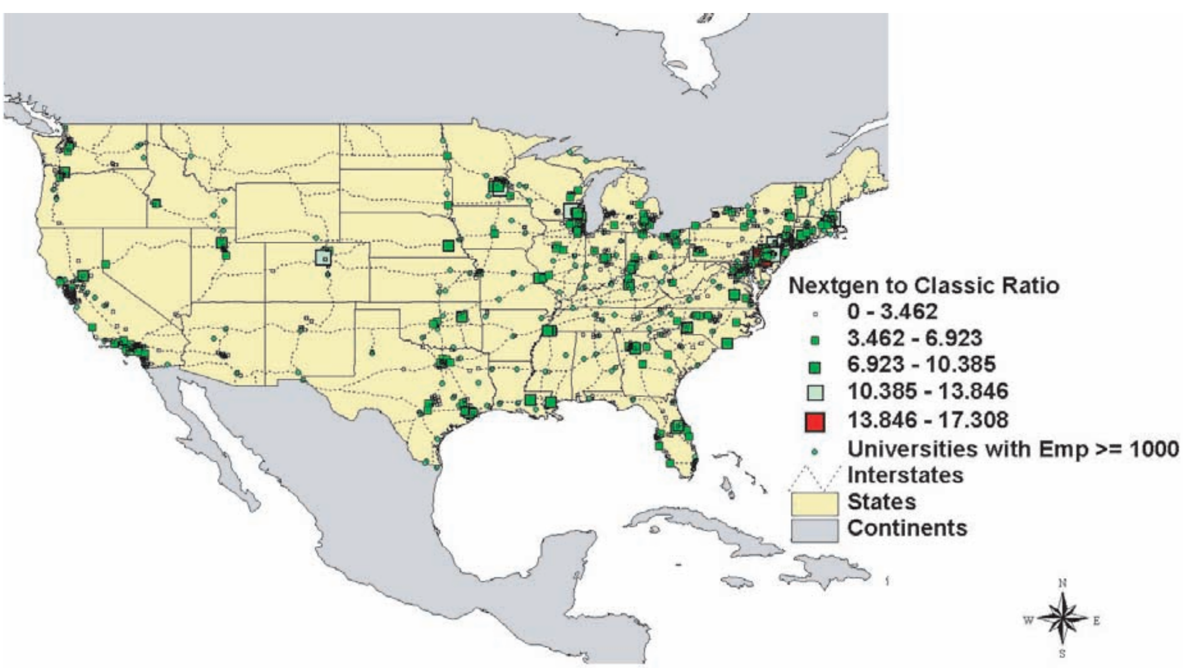
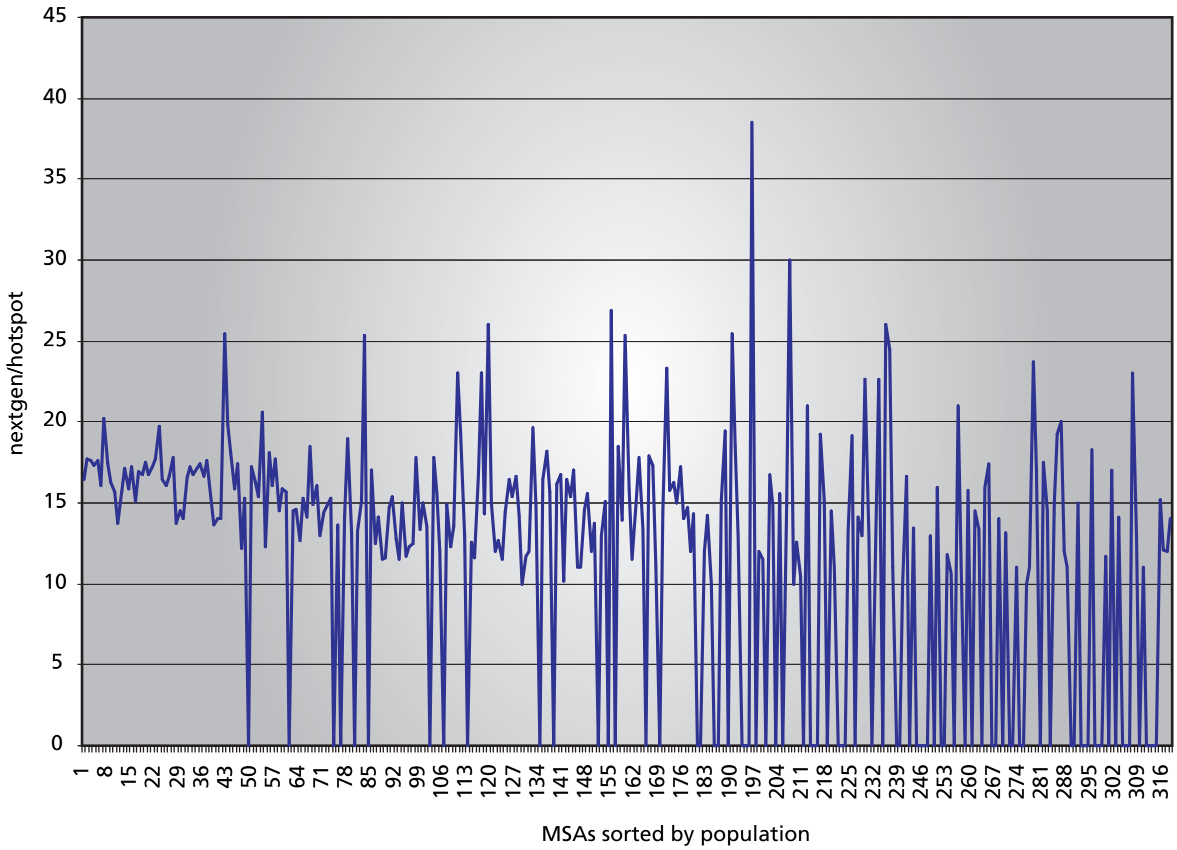


FIGURE 22

Citing-to-Cited Patent Ratios by MSAs, Ranked from Left to Right in Order of Increasing Population



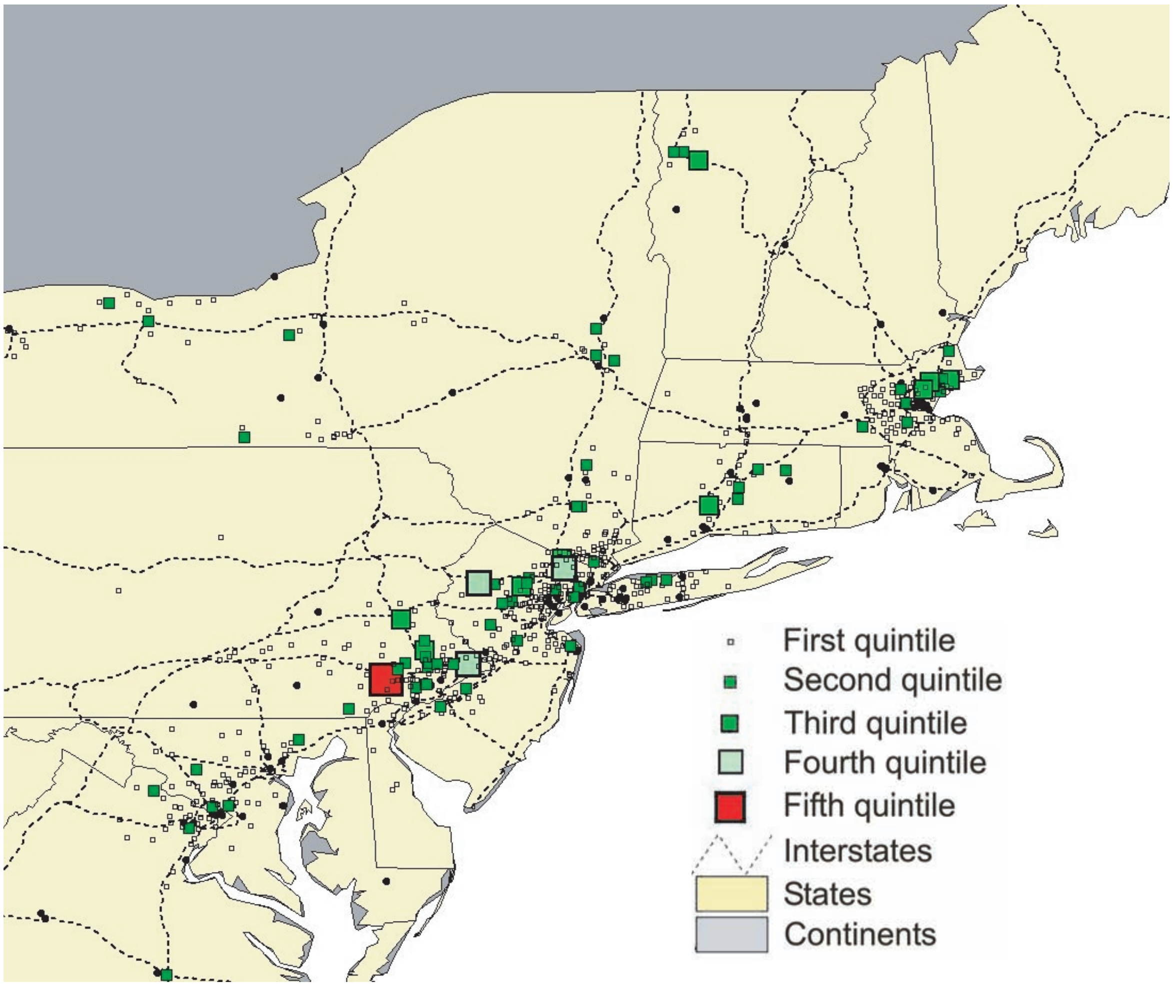
The diversity of the size of the MSAs represented by the emerging technology regions is further evidenced in Figure 22, which shows the citing-to-cited ratio for all MSAs, ranked from smallest to largest in terms of population. The data show no trend at all, emphasizing that emerging technology regions exist across the spectrum of MSA sizes.

Additional geographical characteristics of the emerging technology MSAs become evident when we look at subsections of the country. Figure 23 is a map of emerging technology regions along the Eastern Seaboard. This map strongly suggests that many of these regions are located on the peripheries of leading technology areas (in particular, Washington, D.C., New York, and Boston), as well as along major transportation arteries and population corridors such as the Connecticut River watershed. Further research is required to determine the extent to which emerging technology regions are proximate to leading regions.[4]

4. Of course, as we have seen, some emerging regions are also leading regions. In these cases the relationship is obvious.

FIGURE 23

Emerging Technology Regions, Identified by the Ratio of Citing-to-Cited Patents, Inventor Count, by Cities—Eastern Seaboard



The data also suggest that the infrastructure and the culture of emerging technology regions differ from those of leading technology regions. The profile of leading technology regions suggested by Table 2 is one of large, cosmopolitan cities, mostly off the Bible Belt and on the periphery of "NASCAR Nation." In contrast—in terms of a diverse array of indicators including religious organizations, race tracks, bowling centers, and correctional facilities—the profile of emerging technology regions suggested by Table 5 is one much closer to being representative of MSAs nationwide.

It is striking, however, that the emerging technology regions not only claim more than their share of emerging technology patents (which we would expect, as this count is in the numerator of the ratio), but also lead in hot patent counts (which is surprising, as this count is in the denominator of the ratio). The emerging regions started out somewhat ahead of comparable small MSAs in the country, and are moving forward at a faster pace. This increasing returns to scale (or the "rich get richer") story is a familiar one in economic geography. Although the story does not hold for most of the large leading technology regions, initial evidence indicates that it may apply to the relatively smaller emerging technology regions.

With regard to most of the variables (other than patents) examined in our study, the emerging technology regions do not appear to differ significantly from other regions. Surprisingly, firms in these regions have received significantly fewer SBIR Phase I and Phase II awards than would be expected. This striking finding requires additional research to be clarified. It seems to support the notion that SBIR awards are sought by companies that do not have access to the other forms of early stage finance that predominate in leading and, possibly, emerging technology regions.

5. Summary of Findings

Our study of regional innovative capacity in the United States has yielded the following findings:

Although levels of innovation activity are highly concentrated in a few regions (Table 1, Figure 20) emergent innovation activity is broadly distributed throughout the country (Table 4, Figure 21). The intensity of patent productivity and venture capital activity in the San Francisco Bay area, Austin, the New York metropolitan region, and greater Boston that is evident in Figures 19 and 20 is not surprising. Yet other regions less well known for technology-based innovation also emerge as regions with high levels of patenting. The picture is dramatically different when we look at the cited-to-citing ratio (Figure 21). In shifting the focus from levels of inventive activity to rates of change, it becomes clear that science-based innovation is an activity that involves regions across the United States. This is a core finding in the report.

The extent of the concentration of innovative processes is at least as great within states (and MSAs) as it is between states (and MSAs).

In a number of large MSAs, emergent innovative activity is taking place in urban peripheries and in small to mid-size cities rather than in established locales. To gain a better understanding of the factors that may play a role in making an MSA an emergent region and to differentiate emergent regions from other regions, we grouped the data into three categories and compared each group in terms of all the variables used in the correlation analysis, including population. The first group includes all MSAs for which the citing-to-cited patent ratio is equal to zero, the second group contains all the MSAs that fall into the 85th percentile based on the ratio, and the third group includes all remaining MSAs. Emergent regions are defined for this analysis as MSAs that rank in the top 10 percent according to the ratio. This percentage was selected by plotting all of the observations ranked in ascending order by citing-to-cited patent ratio. The plot shows a modest linear increase along the ranking with an inflection point after the 85th percentile where the ratios begin to increase exponentially. From the analysis, emergent regions are much smaller than leading regions, and slightly smaller than MSAs overall. However, emergent regions are substantially larger, on average, than MSAs that received no hot patents or emerging technology patents.

Clearly the economic context of a region and the availability of business services (such as patent lawyers, research facilities, management consulting services, architectural services, and engineering services) are positively associated with innovative capacity when innovation is measured by patent counts. This supports prior research on the determinants of regional innovation and the finding that specialized services play a role in facilitating innovation in a region. The importance of universities and other factors that are often cited as creating knowledge spillovers do not turn out to be significant in the analysis. This might be explained by the fact that the data used in this analysis simply count of the number of universities and colleges within each MSA, ignoring the attributes associated with each institution. Different findings are likely to emerge when these characteristics—for example, enrollment, research dollars, areas of specialization, and so forth—are considered. When colleges and universities have strong programs in science and engineering, they are more likely to have an impact on technology innovation in an area, but this was not measured here. The coefficients associated with ATP awards are also moderately strong and positive. Two factors that appear to have negative, although weak, effects on innovation are religious organizations and racetracks.

The picture changes considerably when we use the ratio of citing-to-cited patents as a measure of emergent capability in technology-based innovation. In this context, the factor that most highly correlates with emergence of regional technological capability is the presence of universities and colleges and of business incubators.

6. Future Work and Data Infrastructure Recommendations

6.1. RESEARCH

Although the data presented in this report provide some novel insights concerning the geography of innovation in the United States, the primary intention of the report is to describe a methodology whose further development could lead to a far more comprehensive and robust understanding of the determinants of regional innovative capacity.

Five directions for further research are particularly worth noting:

- **Validation of the CHI Research method of identifying emerging technology clusters.** This report has emphasized the value of the CHI Research methodology in contemporaneous identification of emergent technology clusters. A valuable next step would be to use historical data to check the validity of the method. To establish that the emergent technology clusters identified by the CHI Research methodology are, indeed, more likely to generate new innovations requires a retrospective study.

- **Validation of the proposed method to identify emergent technology regions.** The same argument holds for regions. In this report we have identified emergent technology regions by the ratio of cited-to-citing patents, among those in emerging technology clusters. Other ways of identifying emerging technology regions are possible, using the same data. Studies using different measures and employing the measures retrospectively would be of value.

- **Expand the set of policy variables considered.** This study considered only three policy variables: ATP-award recipient companies, SBIR-award recipient companies, and business incubators. Clearly, many more policy instruments exist. Further study could advance the work we have presented by expanding the set of policy variables considered.

- **Apply the method to non-U.S. regions.** The methodology presented allows for the study of the flow of technology from region to region over time. In the twenty-first century, these flows are more likely to cross national boundaries than they are to stay within them. Considerable policy-relevant information could be produced by applying the methodology presented in this report beyond the United States to a set of regions distributed globally.

- **Apply techniques to establish causality.** New methods, particularly GIS tools, permit the creation of different and better-quality data sets pertaining to regional innovation than have existed in the past. Use of these new data sets with new spatial econometric techniques or other advanced inferential approaches has the potential to yield valuable results concerning causality—the determinants of regional economic capacity. Understanding the relative importance of the various factors described in this report as drivers of regional innovation would represent a major empirical advance in this field.

6.2. DATA

Deficiencies in existing data sources were encountered by the research team during this project. As improvements are made in available sources, it may enhance the capacity of researchers in the future to more accurately identify regions with emergent technological capabilities.

In 1982, the Small Business Administration published a unique data set consisting of counts of actual innovations brought to market for which geographical origin was given. The data were gathered from interviews and from exhaustive study of trade journals. Although the SBA innovation count database has proved a lasting resource, it has not been updated in 20 years. In the European Union and elsewhere policymakers have moved forward aggressively to develop data infrastructures relevant for twenty-first century decisionmaking.

The technological categories employed by the Census Bureau[1] are useful for a coarse-grained assessment of economic activity. They match poorly to the core technology spaces, however, that define the strategic landscape for technology entrepreneurs, corporations, and, increasingly, regional planners. A capability to monitor the dynamics of core technologies both within the United States (in a manner prototyped in this report) and internationally from one region to another would be useful.

This report provides a start for specifying the types of data that could be collected and analyzed.

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1. In particular, the Standard Industrial Classification (SIC) codes and the more recently developed North American Industry Classification System (NAICS) codes.

Appendix A. Geographic Information Systems (GIS) Techniques

A geographic information system (GIS) is a powerful analytical tool with multiple capabilities. As its name implies, it is an information system that uses spatial data.

With a GIS, an individual can store data, perform analytical functions on the data, visualize the data and the results of analysis, and query for information. One can think of the system as an interactive mapping, database, and analytical engine.

The GIS has a spatial orientation. All of the data used in a GIS have a geographic reference. A GIS has two main data types, raster and vector. First, we will define a vector data type. The vector data type comes in three subdata types: point-based, line-based, and polygon. Each data type has a table that stores attribute values. Attributes represent spatial objects that are being mapped. The values in the attribute table are accessed using an index table. The use of index tables is internal to a specific GIS and thus is opaque to end users. The combination of an attribute table and its index table, combined with its geographic representation, is referred to as a theme. For example, a road network can be shown as a line theme with its attribute table and its spatial representation. Any of the numeric attributes in the table can be visualized by mapping that attribute's value in the GIS software. For example, the number of lanes in a road network line theme can be shown as lines of different thicknesses on the map.

Point-based data have geographic coordinates (for example, latitude and longitude) and relate to a unique location on the globe. Each point will have a set of attributes that can be mapped or analyzed. The physical location of business establishments (for instance, patent law offices or chemical plants) is a point theme and some of the attributes that may be associated with each establishment include employment size, sales volume, and production capacity.

Polygons represent the spatial extent of data in two dimensions, such as census blocks, counties, zip code areas, MSAs, states, and nations. The attribute tables for polygon data store values that are properties of the polygon. For example, a county polygon theme table can have values for population levels, income levels, and related categories.

Raster is a method of storing, processing, and display of spatial data. It consists of an area covered with an evenly spaced rectangular grid with rows and columns. Each cell in the grid has an implicit location and stores an attribute value that represents a specific characteristic of the area under study. The spatial location of each cell is implicitly contained within the ordering of the matrix, as compared to the vector structure, which stores topology explicitly. In addition, raster data is an abstraction of the real world, where spatial data is expressed as a matrix of cells or pixels. With raster data model, spatial data is not continuous but represented in discrete units. This makes such data suitable for certain types of spatial representation, in particular overlays or area calculations.

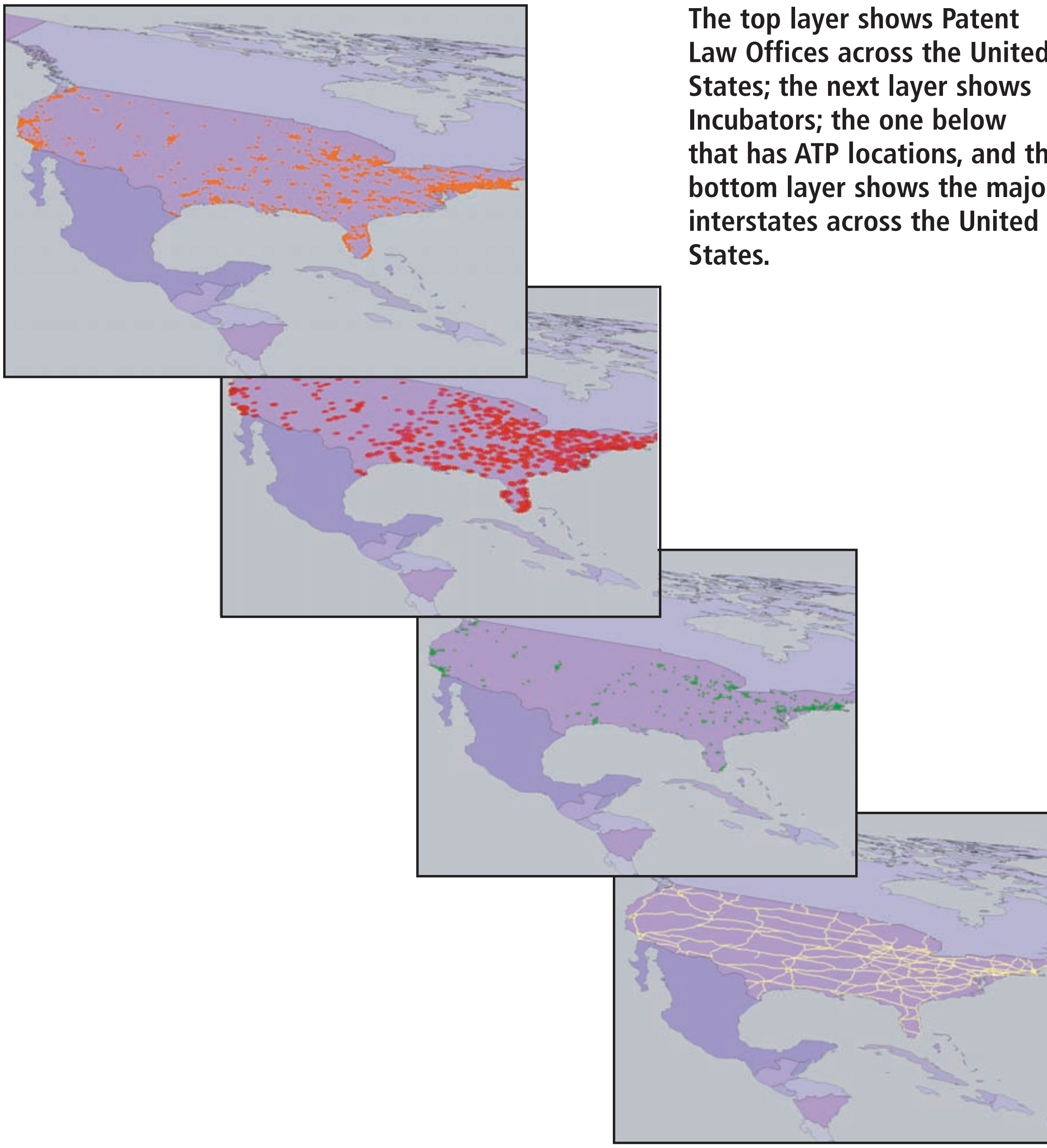
Raster data are generated from the vector data by carrying out a density computation of the underlying physical locations or of an attribute associated with that theme. Although vector data are defined either as a point, a line, or an area, raster data represent spatial aggregation as a density value of an attribute—for example, population density, business establishment density, and road density.

The GIS also allows one to map multiple themes in a view: each succeeding theme is laid on top of the one before (see Figure A1). Each of these themes is called a layer. Such layered data can be analyzed using spatial analysis tools. The results can then be combined by subjecting them to various mathematical operators, and the output can be displayed as another layer—for example, patent law firms, NBIA, ATP awards, road network, or continents.

Figure A2 is a map of Manhattan (New York, New York) that displays the density of fiber optic cable along with the locations of ATP award winners and R&D labs. The map clearly shows that the ATP award winners are located along major fiber optic trunk lines, compared to the large number of R&D facilities (including routing medical testing laboratories, and the like) that are evenly distributed across the landscape.

FIGURE A1

Multiple Layers with Same Geographic References



The top layer shows Patent Law Offices across the United States; the next layer shows Incubators; the one below that has ATP locations, and the bottom layer shows the major interstates across the United States.

FIGURE A2

Fiber Optic Cable, ATP Award Winners, and R&D Laboratories, New York Metropolitan Area

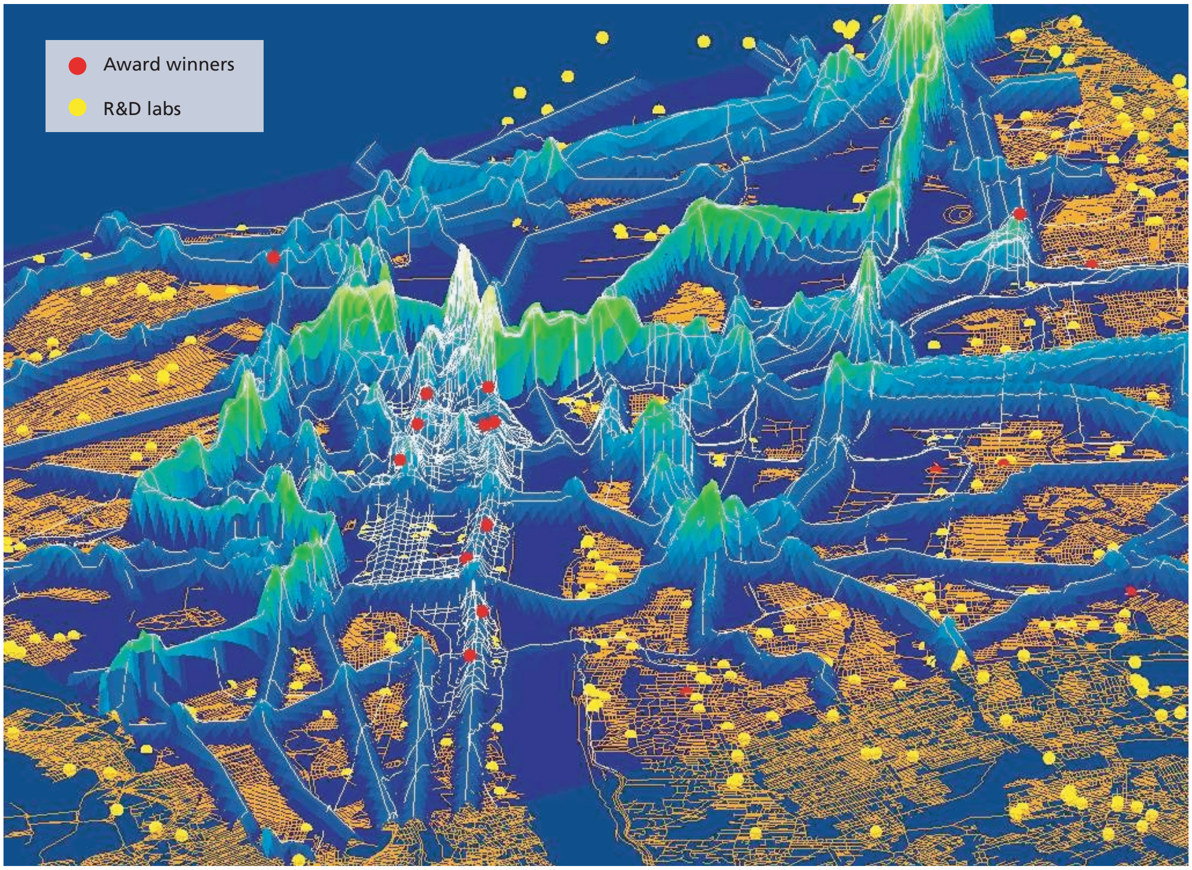


Figure A2 shows the Manhattan area of New York along with the density of information infrastructure, ATP award winners, and R&D labs. The map shows that ATP award winners are located along major fiber optic trunk lines, while the large number of R&D facilities is evenly distributed across the landscape.

Data sources: GMU project on critical infrastructure mapping, ESRI Business Analyst.

Appendix B. North American Industry Classification System (NAICS) Industry Descriptions

Architectural services (541310). This industry comprises establishments primarily engaged in planning and designing residential, institutional, leisure, commercial, and industrial buildings and structures by applying knowledge of design, construction procedures, zoning regulations, building codes, and building materials.

Bookstore (451211). This industry comprises establishments primarily engaged in retailing new books.

Bowling center (713950). This industry comprises establishments engaged in operating bowling centers. These establishments often provide food and beverage services.

Business associations (813910). This industry comprises establishments primarily engaged in promoting the business interests of their members. These establishments may conduct research on new products and services; develop market statistics; sponsor quality and certification standards; lobby public officials; or publish newsletters, books, or periodicals for distribution to their members.

Civic and social organization (813410). This industry comprises establishments primarily engaged in promoting the civic and social interests of their members. Establishments in this industry may operate bars and restaurants for their members.

Correctional institutions (922140). This industry comprises government establishments primarily engaged in managing and operating correctional institutions. The facility is generally designed for the confinement, correction, and rehabilitation of adult or juvenile offenders sentenced by a court.

Engineering services (541330). This industry comprises establishments primarily engaged in applying physical laws and principles of engineering in the design, development, and utilization of machines, materials, instruments, structures, processes, and systems. The assignments undertaken by these establishments may involve any of the following activities: provision of advice, preparation of feasibility studies, preparation of preliminary and final plans and designs, provision of technical services during the construction or installation phase, inspection and evaluation of engineering projects, and related services.

Hobby, toy, and game stores (451120). This industry comprises establishments primarily engaged in retailing new toys, games, and hobby and craft supplies (except needlecraft).

IT-software companies (541511).[1] This U.S. industry comprises establishments primarily engaged in writing, modifying, testing, and supporting software to meet the needs of a particular customer.

Live band/orchestra (711130).[2] This industry comprises (1) groups primarily engaged in producing live musical entertainment (except theatrical musical or opera productions), and (2) independent (that is, freelance) artists primarily engaged in providing live musical entertainment. Musical groups and artists may perform in front of a live audience or in a studio, and may or may not operate their own facilities for staging their shows.

Live theater (711310). This industry comprises establishments primarily engaged in (1) organizing, promoting, or managing live performing arts productions, sports events, and similar events, such as state fairs, county fairs, agricultural fairs, concerts, and festivals, held in facilities that they manage and operate, or (2) managing and providing the staff to operate arenas, stadiums, theaters, or other related facilities for rent to other promoters.

Management consulting services (54161). This industry comprises establishments primarily engaged in providing advice and assistance to businesses and other organizations on management issues, such as strategic and organizational planning; financial planning and budgeting; marketing objectives and policies; human resource policies, practices, and planning; production scheduling; and control planning.

Management services (561110).[3] This industry comprises establishments primarily engaged in providing a range of day-to-day office administrative services, such as financial planning; billing and recordkeeping; personnel; and physical distribution and logistics for others on a contract or fee basis. These establishments do not provide operating staff to carry out the complete operations of a business.

Museums and art galleries (712110). This industry comprises establishments primarily engaged in the preservation and exhibition of objects of historical, cultural, or educational value.

Physical research facility (541710).[4] This industry comprises establishments primarily engaged in conducting research and experimental development in the physical, engineering,

1. NAICS title is "Custom Computer Programming Services."
2. NAICS title is "Musical Groups and Artists."
3. NAICS title is "Office Administrative Services."
4. NAICS title is "Research and Development in the Physical, Engineering, and Life Sciences."

and life sciences, such as agriculture, electronics, environmental, biology, botany, biotechnology, computers, chemistry, food, fisheries, forests, geology, health, mathematics, medicine, oceanography, pharmacy, physics, veterinary science, and other allied subjects.

Racetracks (711212). This industry comprises establishments primarily engaged in operating racetracks. These establishments may also present or promote the events, such as auto, dog, and horse races, held in these facilities.

Religious organizations (813110). This industry comprises (1) establishments primarily engaged in operating religious organizations, such as churches, religious temples, and monasteries, or (2) establishments primarily engaged in administering an organized religion or promoting religious activities.

Testing laboratories (541380). This industry comprises establishments primarily engaged in performing physical, chemical, and other analytical testing services, such as acoustics or vibration testing, assaying, biological testing (except medical and veterinary), calibration testing, electrical and electronic testing, geotechnical testing, mechanical testing, nondestructive testing, or thermal testing. The testing may occur in a laboratory or on site.

Universities and colleges (611310).[5] This industry comprises establishments primarily engaged in furnishing academic courses and granting degrees at baccalaureate or graduate levels. The requirement for admission is at least a high school diploma or equivalent general academic training. Instruction may be provided in diverse settings, such as the establishment or client's training facilities, educational institutions, the workplace, or the home, and through correspondence, television, the Internet, or other means.

5. NAICS title is "Colleges, Universities, and Professional Schools."

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