

Knowledge Networks and Technical Invention in America's Metro Areas: A Paradigm for High Technology Economic Development

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This research builds on our previous work on technology led economic development published in the Spring 2002 edition of the IEDC Economic Development Journal. The author has been a private development consultant in North America since 1997. Prior to that, he led in economic development programs at the regional and local levels in Louisiana, Texas, Oklahoma and Georgia for 20 years. Bee holds an MA in economic geography from the University of Georgia and an undergraduate degree in geography and urban studies from Youngstown State University.

Abstract

The presence of high technology jobs defined the regional winners in economic growth during the last decade. Countless communities around the USA tried to clone Silicon Valley to accelerate their own growth rates but these programs consistently failed. This research demonstrates that all innovation is not tied to microchips and silicon. Seven other technologies are growing within the United States. Each of these technologies forms a "knowledge network" of innovations that resemble the pareto distribution of national wealth, suggesting that technology behaves according to the principles of social networks. Patent data refutes the folklore that small companies are more innovative than large ones. Rapid growth among small companies might stem from better organization or business processes, but it doesn't appear to stem from higher rates of technical invention. The principal distinction among innovative regions like Silicon Valley and Boston are the number of large corporate R&D centers (not their university infrastructures nor the invention rates among their small companies & individual inventors). Communities must evaluate their strengths in each of the 8 knowledge networks to determine the best strategy for accelerating their technology growth. Policy measures that stabilize the volatility of technical labor markets should lead to a wider diffusion of technology, as should measures that reward licensing and transactions in technology.

Introduction

Ross DeVol and colleagues at the Milken Institute demonstrated the close relationship between the concentration of high-technology jobs and community growth in their 1999 landmark study.¹ DeVol found that two-thirds of economic growth nationally during the 1990's stemmed from high-technology industry. Technology growth was uneven with large concentrations in a small number of communities. Communities with technology grew much faster than those that lacked a tech sector. Milken fashioned a "Tech-Pole" concept to describe the communities with concentrations of technology.

Economists since Alfred Marshall have been unable to explain fully, by either differentials in production costs or market locations, certain concentrations of industrial production including high technology production. Marshall coined the term "agglomeration economies" to explain the driver behind these concentrations. Peter Hall, a British geographer who has studied patterns of innovation, discovered that technical innovation clusters spatially because commercial breakthroughs stem from long "chains of inventions", not from a single revolutionary idea. Innovation chains appeared in Glasgow shipbuilding in the 1800's, in the Manchester textile revolution a generation later and they exist now in Silicon Valley, Boston and present-day techpoles². Technology companies cluster because new technologies build on previous innovations.

While production and employment statistics are valid measures of technology growth and concentration, they don't measure the potential for development of technology clusters. Technology (the application of science to commerce) is certainly tied to advances in scientific knowledge--³ but how close are the ties?

Patents are the best measure of a region's potential to turn science into commercial inventions. Stern and Porter, working at the National Bureau of Economic Research, concluded that patent data is far more predictive of technological production than academic research.⁴ Adam Jaffe confirmed in a separate study that patents are the better measure of technological innovation⁵. Our prior research showed a statistically significant link between patent output and regional wealth where variations in the number of patents explained about a third of the differences in income among 317 metro areas (See Figure 1). Patented technologies are the best known measure for gauging the technology potential in America's metro areas.

Patents and Technology

The US Patent and Trademark Office (USPTO) assigns patents to one of 426 technology classes. These classes are complex and not distinct to particular industries (A plastics company, for example, might have inventions in any one of 9 polymer materials, in coatings, in distillation, in catalysts or in 100 other physical or chemical classes). The National Bureau of Economic Research recently grouped patents into 36 aggregations.

These aggregations allow researchers to study geographic patterns of invention, as well as “spillovers” of patents between universities and industries and among industries, and to correlate industry employment to patent flows. Tamerica combined the patent data from NBER with geographic files from the USPTO to look at technology in US metro areas. Patents granted to inventors in 318 urban areas between 1990-99 were summed for each NBER aggregation. Summation eliminates the annual variations that distort trends. This database of patent information encompasses 92 percent of the total patents issued during the period to US firms (only 8 percent of US inventions occur outside of metropolitan areas).

Three M's, 3 C's and 2 E's

Principal components analysis (a multivariate statistical technique) of the 318 metro areas identified 8 “Knowledge Networks” comprising 68 percent of the patents (the 8 networks and their respective subclasses are shown in Table 1). Each of the Knowledge Networks has grown significantly in the last 15 years, although growth in some technologies is far faster than others (See Figure 2). While it is tempting to suggest that all technology revolves around computer chips and electronics, “older” technologies, such as inorganic chemistry, still produce significant streams of commercial invention. The 8 Knowledge Networks can be abbreviated as *The 3 M's, 3 C's and 2 E's*.

The First “E” The largest cluster, in terms of patents, consists of innovations in the production of electronic devices. Nine of the 36 classes are grouped geographically in a cluster we call **Electronics and Electrical Devices**. These technologies consist of semiconductors, computers, communications devices, lighting, power systems and related activities. The core knowledge base in this network is electrical engineering and physics. All of the components of this cluster, except for semiconductors and nuclear technologies, are accelerating their production of patents (See Table 2). This cluster grew from 30 percent of all patents in 1990 to nearly 40 percent by the end of the decade (See Figure 3). Much of the pattern observed by Milken in the 1990's was a manifestation of rapid growth in this field.

The Second “E” revolves around **Entertainment and Fashion**. Furniture and home furnishings and apparel-textile inventions, technologies that ushered in the industrial revolution two centuries ago, continue to provide new commercial opportunities. Interestingly, each of the 3 components of this tech cluster are accelerating their patent output.

The First “M” of **Medical technologies** revolves around drugs & biotechnology, but also include surgical instruments and computer peripherals. All of the components of this network are accelerating their production of patents (Table 2). The total number of patents in this cluster doubled within the decade as did its proportion of total patents.

The Second “M” is not considered “high tech” in today’s parlance, since the heyday of **mechanical invention** was the era of Henry Ford. Inventions in motors, engines and transportation continue to produce new commercial products and processes. Some of the components (motors, engines and misc. mechanical patents) are growing steadily at 2 percent per year but other industries in this network are accelerating their patent output.

The Third “M” of **Mining** technologies revolve around wells (oil and gas) and earth work (metals mining). As these technologies are linked to natural resources, the locations of mining technologies are far different than those in other technologies.

The First “C” Organic chemistry spawned commercial opportunities beginning a hundred years ago with the development of products like Bayer’s aspirin. Innovations continue in the production of plastic and rubber (polymers), other organic compounds, gases and food-textile chemistry. Core knowledge in this network consists of chemistry and chemical engineering. Two of the network’s component industries are accelerating while two others are steady (Table 2).

The Second “C” of Inorganic chemistry has its own network. Patents in optics, miscellaneous chemicals, and materials processing cluster geographically. Patent output in optics, a hot academic area, are steady while output of patents in miscellaneous chemicals is slowing (Table 2).

The Third “C” A separate network of **Coatings** and metalworking companies has evolved in geographic space. Although coatings technologies are emerging in semiconductors and polymers, the strongest synergy remains between coatings and metalworking. Patents in metalworking are accelerating while output in coatings is steady.

Footloose Technologies A seventh of the patent classes do not cluster geographically. Miscellaneous drugs and medical devices, heating equipment and inventions in agriculture, many tied to rural land grant institutions, are example of footloose technologies that remain outside the eight knowledge networks.

Geographic Concentrations of Technology

Vilfredo Pareto discovered in 1897 that the balance between rich and poor is remarkably similar across countries, despite vast differences in resources, educational attainments, or economic bases. Unlike natural phenomena like height or weight, wealth is not normally distributed. Wealth follows a “fat-tail” curve with a preponderance of poor citizens, a greatly diminished middle class and a small number of wealthy families that command great resources. In the US, for instance, it’s estimated that the wealthiest 20 percent of families control 80 percent of the nation’s wealth. These “fat-tail” distributions bear Pareto’s name. Social scientists have discovered that Pareto curves describe a host of social and economic networks, besides income, that result from individuals interacting in society.

The distribution of innovation among America's metro areas also follows pareto curves, whether measured by gross patents or by patents adjusted for differences in population (See Figure 4). The Pareto pattern holds for each of the eight knowledge networks, with only minor differences in the steepness of the curves.

Network Effects among Technology Clusters

Economists recognize that high-technology products exhibit “network effects ” that spawn their rapid growth. Network effects work this way: A new technology, such as the fax machine, is introduced into the market and a few users find it of value because of their sophisticated needs (the fax machine, for example, was a great improvement over the telex for Japanese companies which preferred to communicate to their global networks of offices using the kanji characters that are not part of the roman alphabet used on the telex keyboard). As the network of users grows, the technology gains value for everyone in the network and this stimulates further purchases and further growth in the network. Network growth therefore bestows higher economic returns to all of the participants, including the early adopters of the technology, without further investment on their parts.

Recent research in France and Poland demonstrate how wealth concentrates into pareto distributions through network effects.⁶ Thomas Schelling demonstrated that network effects lead to geographic concentrations in social networks (in racial patterns of housing, for instance), even in the absence of racism or rigid government housing policies.

Technical innovation in metro areas appear, based on their pareto distributions, to exhibit these same network effects. Metro areas that are nodes in one of the 8 knowledge networks generate value for all patent holders in the node through these effects. Nodes in these networks witness rising standards of living through the acceleration of innovation. Network effects explain the gap in economic growth that occurred during the 1990's within America's metropolitan areas.

Bouchard's work with wealth suggests that distributions become more uniform when trade is encouraged and when investment returns are stable. Volatility in technical labor markets (a surrogate measure for money in this case) appears to explain some of the concentrations of innovations among knowledge networks. Employment patterns in oil and gas, the central industry in the mining network, is a great example of how market volatility affects the concentration of technical talent in a network. Tech workers in a volatile labor market do not want to remain in a small node where alternative job opportunities are few. When major oil and gas companies restructured in the 1990's, they consolidated offices for New Orleans, Lafayette, Tulsa and Midland (other nodes in the mining network) into Houston. When workers relocated to Houston, they became reluctant to accept transfers out of town, even for promotions with better salary, since they had fewer job alternatives in the smaller nodes of the network. This reluctance led to a further concentration of technical workers, and patent production, in Houston.

Bouchard and Mezard discovered that networks of wealth reach a “tipping point” under extreme volatility where an elite few families control most of a society’s wealth. This research has profound implications for knowledge networks. Can extreme volatility in technology job markets create a migration of knowledge workers into a handful of nodes? Can policy reforms that accelerate the exchange of knowledge, through rewards for licensing, lead to more uniform distributions of technology, and hence of wealth, in America? The Stanford Boyer patent on gene splicing is an illustration of this principal. Stanford nixed the idea of awarding an exclusive license on the use of the technical invention that enabled gene splicing. Because of their decision, the biotechnology industry grew rapidly throughout the world, rather than remaining the exclusive purview of a single large company.

The Nifty Sixty Suggests that Knowledge Networks Exhibit Strong Spillover Effects

Since the innovative landscape of America is a collection of 8 Knowledge Networks, how distinct are the networks? Does knowledge from one network spill into others? The leading regions in each technology overlap significantly (See Figure 5). Thirty metros (out of a possible 80) comprise the **3-σ** group (regions that are 3 standard deviations above the mean and among the Top-10 regions in one of the networks). Sixty metros (out of 240 possible communities) encompass the **2-σ** group (among the top 30 regions in one of the network, or 2 standard deviations above the mean). (See Figure 6). These sixty regions comprise 70 percent of the innovation in metropolitan America, conforming to the 80/20 principle in pareto networks. Linkages between engineers and technicians in different industries, through informal networks and through inter-industry hiring patterns, evidently create spillovers of technology between industries.

Half of the **2-σ** communities are located in Ohio, New York, New Jersey, Texas and Wisconsin. The remainder, including research centers like Research Triangle, Boulder, and Madison, Wisconsin, are located among 15 other states. Interestingly, nine of the 3-σ and 2-σ metros lie within 100 miles of New York City, the largest population concentration in the United States. Does the sheer size of a metro area determine its ability to develop technology, as Alan Pred surmised in his Cumulative Causation model? Despite the temptation to attribute the concentration of innovation to external economies

such as hub airports, specialized professional services and major universities, just 45 percent of the variation is explained by size. The Entertainment/Fashion cluster (where market size clearly drives innovation) is most influenced by size while mining (where natural resources are important) is least influenced (see table at left). Factors beyond size of talent pools or size of regional markets are

<i>Correlation between Metro Population and Patent Output in 8 Technology Clusters</i>	
Technology	Correlation (R Square)
Electronics	.303
Medical	.506
Mechanical	.528
Entertainment/Fashion	.857
Organic Chemistry	.448
Inorganic chemistry	.421
Coatings	.530
Mining	.093

driving innovation rates in the 3- σ and 2- σ communities.

The Distribution of Recent Patents in The Nifty Sixty Metros				
Tier	Entities(#)	No. of Patents	Percent of total patents	Avg. patents/ Entity
Prolific (>10 patents/yr)	252	69,768	61%	277
Second Tier (5-10/yr)	153	5,302	5%	35
Third Tier (1-5/yr)	569	5,998	5%	10
Individuals	32,853	32,853	29%	1

Does Small Business Dominate New Technology?

A folklore emerged in America over the last 20 years about the inventiveness of small business. Both economic developers and academicians assume that small business is far more innovative than large companies because of David Birch's research on employment growth rates among small companies. Patent data suggest otherwise (See Table 3). Just 641 entities (companies, universities and government labs) in America produced 55 percent of all patents during the last 5 years while just two-thousand entities (about 3%) produced 70 percent of all patents during the period. Again the distribution follows a pareto, not a normal, curve.

In the 30 largest innovation centers, patents also are concentrated among a small number of companies. Two-hundred fifty entities produce two-thirds of the total patents within these 30 metro areas (See table above). The most prolific innovators, such as IBM and Motorola, have R&D centers in a variety of these innovation centers⁷. What role do universities play among the most prolific innovation centers? Thirty-one of the most prolific centers (9 percent) are university controlled.

Innovative regions have more prolific innovators--not more small businesses. San Jose, the most innovative region in the world, has 100 prolific entities producing 12,800 patents every 5 years (more than the total number of patents in 95 percent of all metro areas). Chicago has 50 producing 5,850 patents. The correlation between employment in startup companies and the output of patents is indeed weak and insignificant (the correlation coefficient of this relationship is .20). Regions that produce new technology need large R&D centers, not a host of workshop inventors and small companies. The emergence of Hewlett Packard is celebrated as the beginning of Silicon Valley, but the region saw major investments in corporate R&D by IBM, Lockheed and Xerox prior to its period of explosive growth during the 1970's.

Research by Christensen at Harvard supports this finding.⁸ Christensen found that new business ventures are far less successful than larger established firms at introducing mass

market innovations. Young companies have advantages in process and culture that allow them to develop better organizational methods for producing and marketing disruptive technologies to niche markets, but large companies, with their commanding resources, are far more successful in bringing innovations to mainstream markets. Small business growth appears to stem from better business dynamics, not from better technology.

The Culture of Innovation

Do some regions have more technology because they possess a culture of innovation? Is there something about the water or the culture in Silicon Valley or Boston that makes these regions so innovative-- or is development a function of the preponderance of corporate R&D centers?

The evidence suggests that innovation among individuals, measured by patents per 100,000 population, varies tremendously among metros. This distribution approaches a normal bell curve (as

opposed to a pareto curve) with nearly as many metros below the average as above it (See Figure 7)⁹. The distribution of patents by individuals appears to follow a different rule than the overall innovation rates in metropolitan areas.

Top Metros in Patents Awarded to Individuals	
Name	Rate (patents/100 k population for 1995-99)
San Jose	87.2
Boulder-Longmont	83.8
Reno	72.2
Greeley, CO	67.5
Orange County, CA	61.5
West Palm Beach, FL	59.8
San Francisco	59.4
Santa Barbara, CA	55.7
Corvallis, OR	55.7
Santa Fe, NM	55.4

Are Universities the Seedbeds of Regional Technology Clusters?

Case studies of technology development in Boston, Austin, and San Jose (written, incidentally, by university researchers) paint the enabling role of MIT, UT, and Stanford in the growth of these clusters. Most economic development programs for technology revolve around accelerating university technology transfers, since the profession assumes that universities are the seedbeds of new technology. Theory suggests that businesses near research universities are better networked with professors and therefore among the first to adopt cutting edge science. If this theory is accurate, patents based on university ideas should emerge first near universities.

Since inventors make claims that their invention improves on previous work (“prior art”), these citations are a means of looking at the temporal and spatial spread of innovations from universities.

An Examination of University “Blockbusters”

We examined university “blockbuster” patents in the semiconductor area to determine whether new innovations cluster near universities. We selected the three university patents with the largest number of claims among semiconductor patents:

- Patent #3,473,160 issued to Stanford Research Institute in 1969 for a “Solid State Logic Array”
- Patent #4,059,461 issued to MIT in 1985 for “Improved Crystallinity of Semiconductor Films”.
- Patent #4,826,808 issued to MIT in 1989 for “Creating a Superconducting Oxide”.

These patents have been cited in 331 other patent applications as “prior art”. They are the most cited of all academic patents in semiconductors (the median number of patent citations in the semiconductor area, incidentally, is 3).

Geographic proximity should result in earlier claims by entities within the same region and more claims ultimately should occur near the university.

MIT Patent # 4,059,461

This patent was cited 16 times during its first 5 years. Of the 16 citations, only one was from Massachusetts (equal to the number of citations from Germany). This patent was ultimately cited 85 times. A fourth of the citations were international, and just 7 (8%) were in Massachusetts. New Jersey and New York, by contrast, account for a fourth of the patent citations.

MIT Patent # 4,826,808

This patent has been cited more times than any other academic work in semiconductors. In its first 5 years, other inventors claimed it 14 times on their patent applications. Of the 14 claims, none were from Massachusetts and 6 were international. In its first 10 years, the patent received 125 claims. Forty percent of the claims are from companies outside the United States; twelve from semiconductor companies in California, and fourteen claims from Massachusetts. Note however that 10 of these claims from Massachusetts were by MIT, the inventor.

Stanford Research Institute Patent # 3,473,160

This patent by SRI developed a “Solid State Logic Array”, a circuitry used in microprocessors. This patent, issued in 1969, is the earliest of university patents in semiconductors. It has received 121 claims since its issue. The patent received no claims within its first 5 years (owing, we suspect, to the smaller size of the commercial semiconductor industry at that time). It received 10 claims in its first 10 years. Of the 10, two were from outside the US and 2 were from California. This patent has received a host of commercial claims since its expiration in 1990. Of the total claims since issuance, 83 are from California companies (77 made after the patent expired).

Conclusions about the Town & Gown Link

Proximity to universities with leading edge research doesn't appear to bestow geographic advantages to local companies, at least in the case of semiconductors. World-class universities like MIT and Stanford have world-wide networks. Companies on the other side of the world are as likely to access their cutting edge research as local companies, if these examples are any indication. The evidence from patent licensing supports this. MIT licenses less than 40 percent of its patent portfolio to companies in Massachusetts. Historical anecdote also shows that the link between basic science and commercialization can be remote in space. The magnetron tube used in radar and microwave ovens was developed by two physicists from Cambridge yet commercialized by MIT and Raytheon in Boston.

Linkages between university science and commerce are clearly stronger in other knowledge networks, however. The scramble by pharma companies to form collaborations with biotech faculty suggests that town and gown links are much stronger in the medicine network than those in semiconductors. Research at the National Science Foundation also suggests that commercial licensing and development of university patents in chemistry is common.

Intel recently opened labs across from Carnegie Mellon, Berkeley and U Washington. “By being close to a university, our researchers in the lab are constantly mingling with fresh graduate students, who are working on their thesis,” notes Mahadev Satyanarayanan, who directs the Intel facility at Carnegie Mellon¹⁰. Satyanarayanan cracks the town and gown code when he observes that, “If your goal is to produce the next car or the next chip and it's more of an engineering problem, then the very scripted, planned environment is the best environment. But in creative thinking, it is the unplanned, unrehearsed that's critical.” Town and gown links are an asset to business because they allow companies to tap young talent with ideas that are too nascent to have evolved into patents. This resource, rather than patent portfolios, is the bait that attracts business investment. In emerging sciences like biotech, the innovation well is deep at universities.

Policy Reforms for Regional Technology Development

Regional technology development is not a simple process. We offer six suggestions, based on this research, to improve the process:

Size doesn't Matter

The size of metro areas explains little of the growth of technology clusters. Silicon Valley, now the largest technology cluster in the world, had more manufacturing workers in apricot processing than in electronics, when its electronic cluster began to jell 50 years ago. Small and mid sized metros can develop effective strategies to stimulate technology growth.

Cluster Strategies

During the 1990's, economic developers employed new tools, such as cluster strategies, to stimulate the formation of technology clusters. Cluster strategy borrows from Michael Porter's work. Porter observed that globally competitive industries, such as those in Silicon Valley, derive their advantage from competition among suppliers and support industries within the region, which in turn is driven by sophisticated customers within the region. The cluster concept attempts to stimulate the formation of agglomerations that drive growth in innovation centers like Silicon Valley. Cluster studies are based on the premise that small and startup companies are the drivers behind the formation of technology clusters. This research, which demonstrates that large corporate R&D centers drive community innovation rates, suggests that an incremental approach based on stimulating small business formation and growth will have limited impact on technology development. Cluster strategies at the community level often require, for political reasons, that communities divide resources among a number of clusters. Since innovation follows the pareto 80/20 formula, lack of focus is a recipe for mediocrity. Technology strategies that focus on becoming a node in one of the 8 knowledge networks should be the goal of technology efforts.

Its not always Microchips

Not all technology development programs should be based on semiconductors and electronics. Its more viable for communities to invest resources in a technology where it has a comparative advantage, rather than start from scratch with the new faddish one. This research suggests that an incremental increase in effort on a broad front, because of the 80/20 rule, is less effective for building sustainable technology clusters than a focus on one technology where a community has innate advantages.

Recruitment Strategies are Important Tools

Talent pools, not university patent portfolios, are the resource that makes urban centers attractive to tech companies. Universities, even strong research centers, become assets for technology development when they offer a large and reliable talent pool of technical

workers. Our preliminary look at blockbuster patents in semiconductors shows that technology spinouts from major universities are not geographically concentrated in the region or state of origin although we have not tested this thesis in networks such as medicine. This preliminary analysis suggests that traditional economic development strategies that include efforts at business attraction and improvements to the regional business climate, are an important component in a regional technology strategy.

Volatility in Technical Labor Markets affects the Diffusion of Technology

Labor market volatility is a brake on the geographic diffusion of technology. Policy reforms that encourage stability stimulate the diffusion of technology. An understanding of this dynamic is also critical to the management of corporate R&D resources.

Federal and State Policy can Encourage Diffusions of Technology

Court decisions, tax and licensing practices that discourage transactions in technology restrain the geographic diffusion of technology. Policy reforms that stimulate such practices spread the wealth effects of technology among a broader range of communities. Likewise, innovations such as the broadband internet, that speed transactions in knowledge, offer a great opportunity to diffuse innovation. States that implement policies to reward licensing through such vehicles as reimbursable tax credits can expect to stimulate technology development.

Table 1
Technology Clusters

Electronics & Electrical Engineering

- Computer hardware & software
- Information storage
- Electrical devices
- Measuring and testing
- Semiconductor devices
- Power systems
- Electrical lighting
- Misc. electrical patents
- Communications

Footloose

- Misc. drugs & medical devices
- Misc. other patent classes
- Heating
- Agriculture, food & husbandry
- Nuclear & X-Rays

Medicine

- Drugs
- Computer peripherals
- Biotechnology
- Surgery & medical instruments

Mechanical

- Motors, engines & parts
- Pipes and joints
- Transportation
- Misc. mechanical patents

Entertainment & Fashion

- Furniture & house furnishings
- Misc. other patents
- Amusement devices
- Apparel & textiles

Organic Chemistry

- Resins
- Organic compounds
- Gas patents
- Ag, food & textile chemistry

Inorganic Chemistry

- Optics
- Misc. chemical patents
- Materials processing & handling

Coatings

- Coatings
- Metal working

Mining

- Earth working
- Wells

FIGURE 1

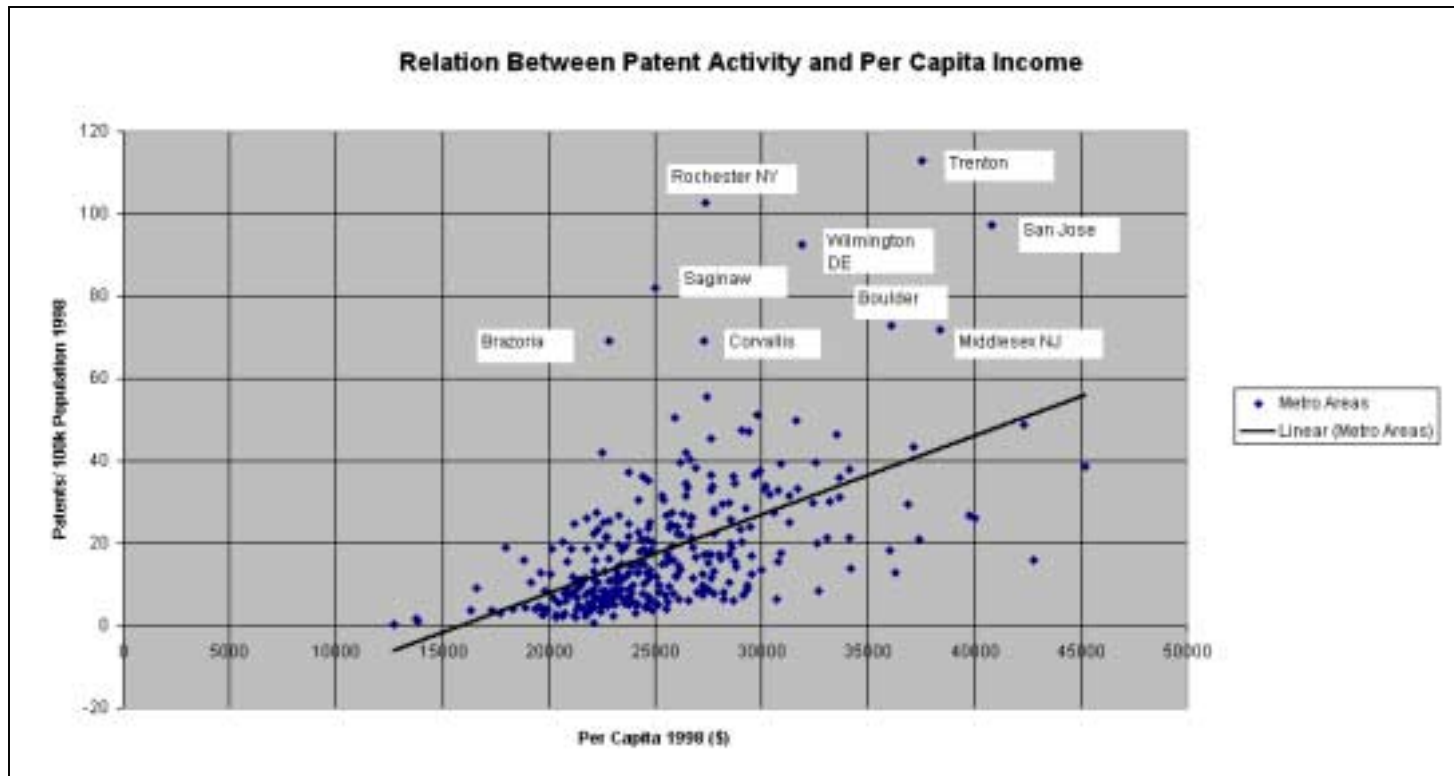


FIGURE 2

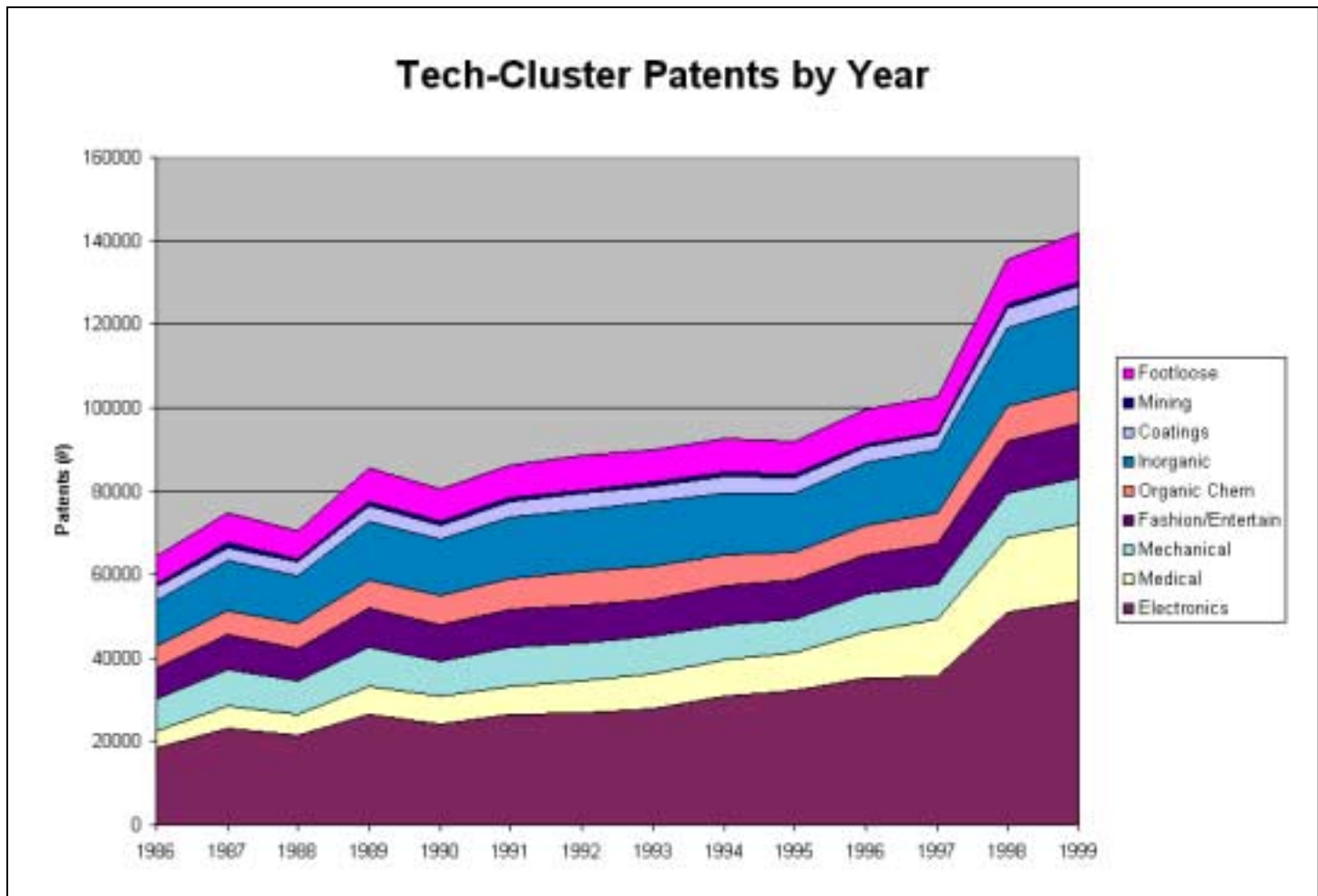


TABLE 2

Patent Trends by Tech Cluster between 1986-1999

Cluster	Accelerators	Deaccelerators	Steady
Electronics	Computer Hardware & software information storage electrical devices power systems misc. electrical patents communications	Semiconductors nuclear & X-rays	Lighting
Medical	Drugs Computer peripherals Biotechnology Surgical/Medical Instruments		
Mechanical	Pipes & joints transportation		Motors & engines Misc. mechanical patents
Fashion/Entertainment	Furniture & House fixtures Misc. other patents Amusement devices Apparel & textiles		
Organic Chemistry	Gas patents Ag., Food & textile chemistry		resins Organic compounds
Inorganic Chemistry		Misc. chemicals	Optics material handling
Coatings	Metalworking		Coatings
Mining	Earth working & wells		

FIGURE 3

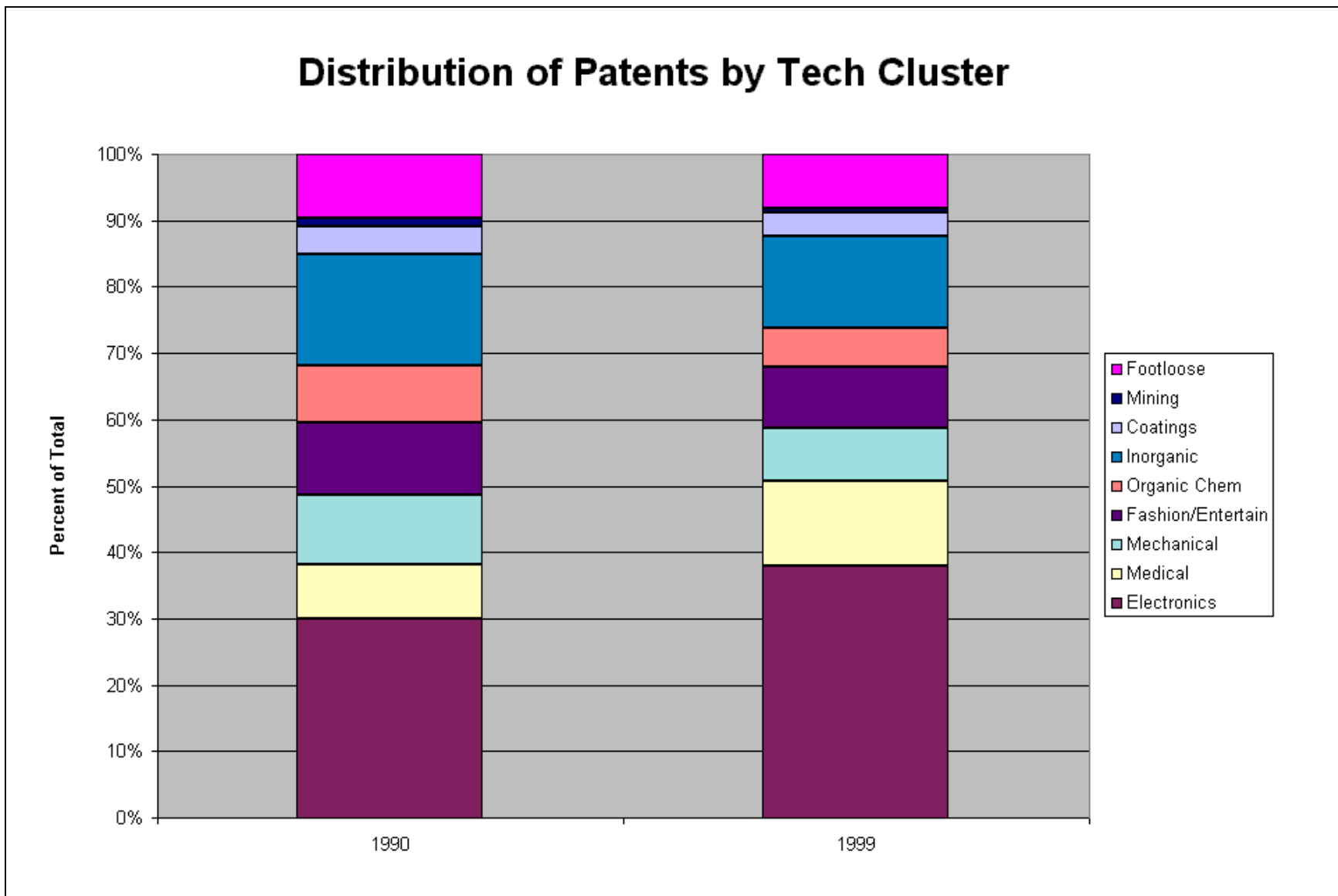


FIGURE 4

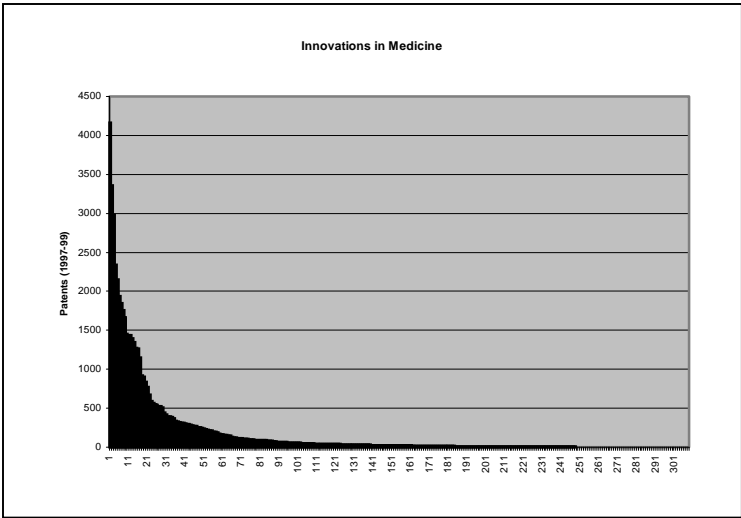
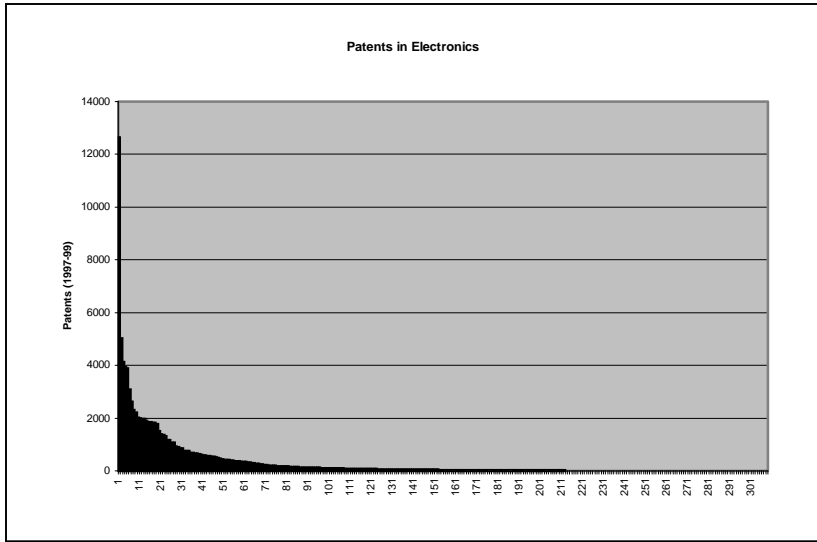
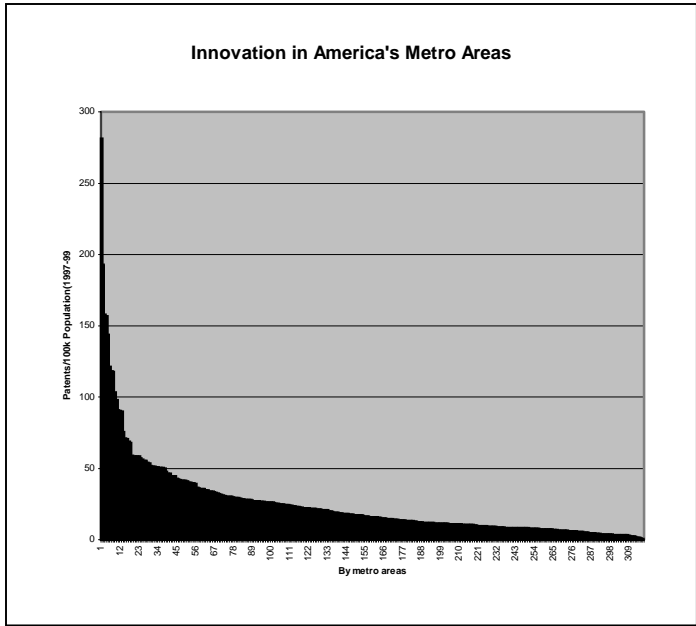
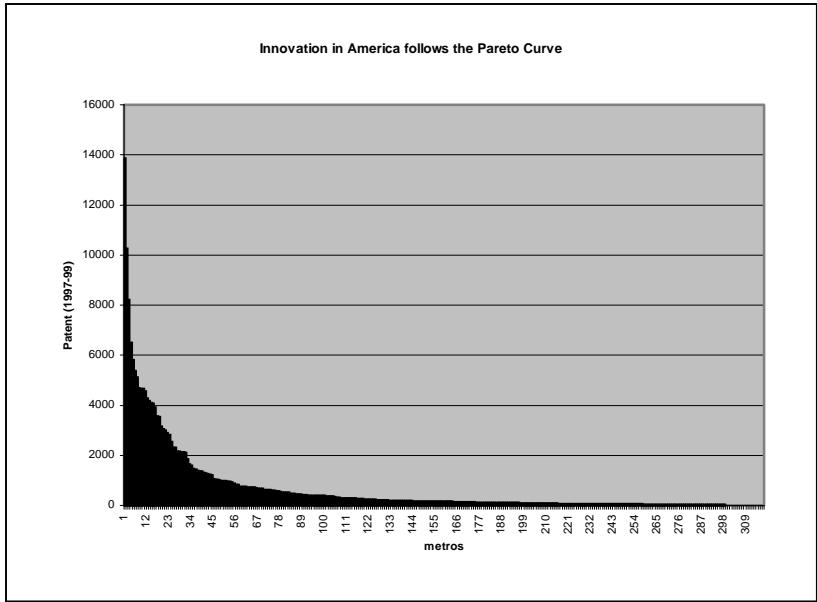


FIGURE 5

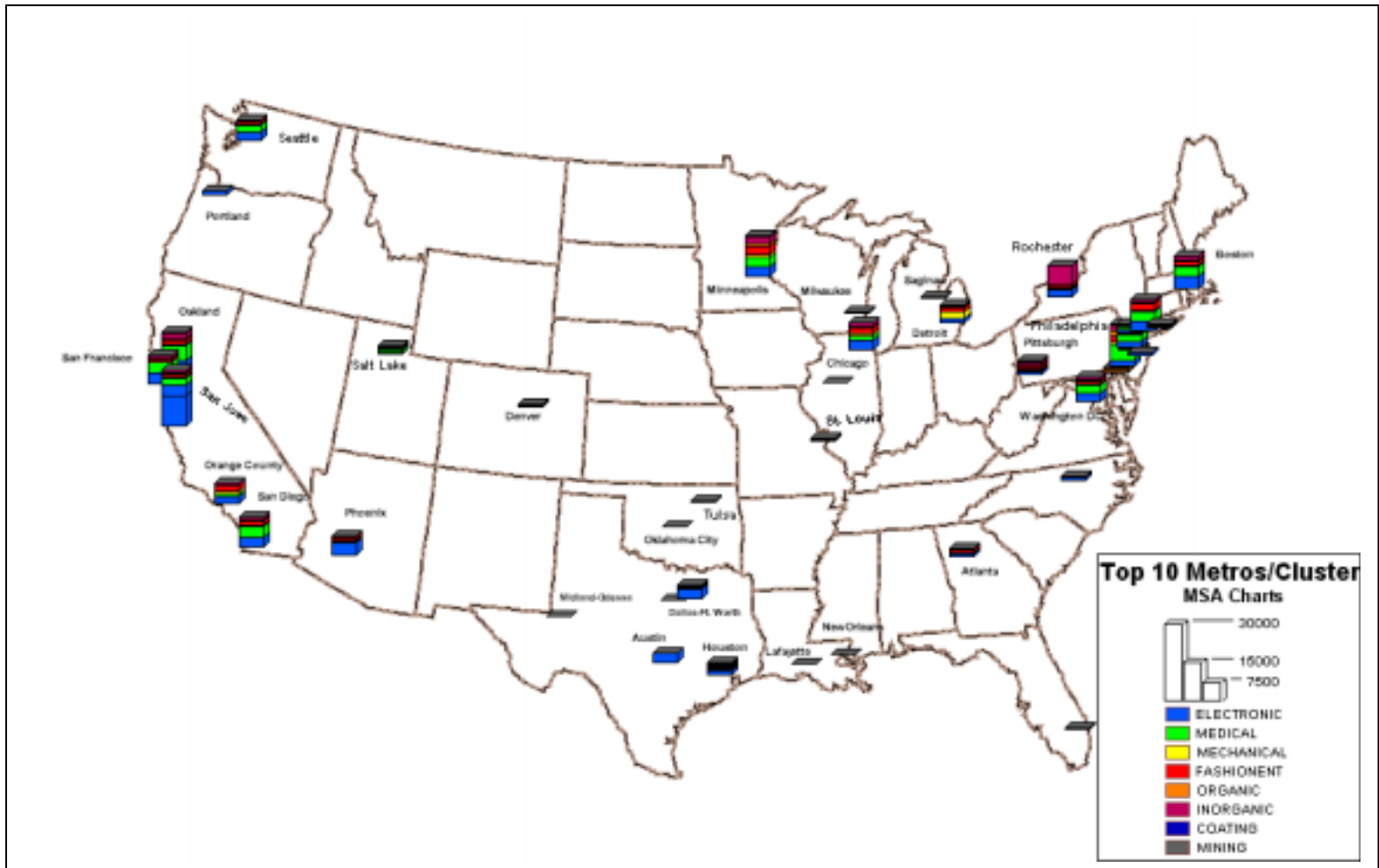


Figure 6

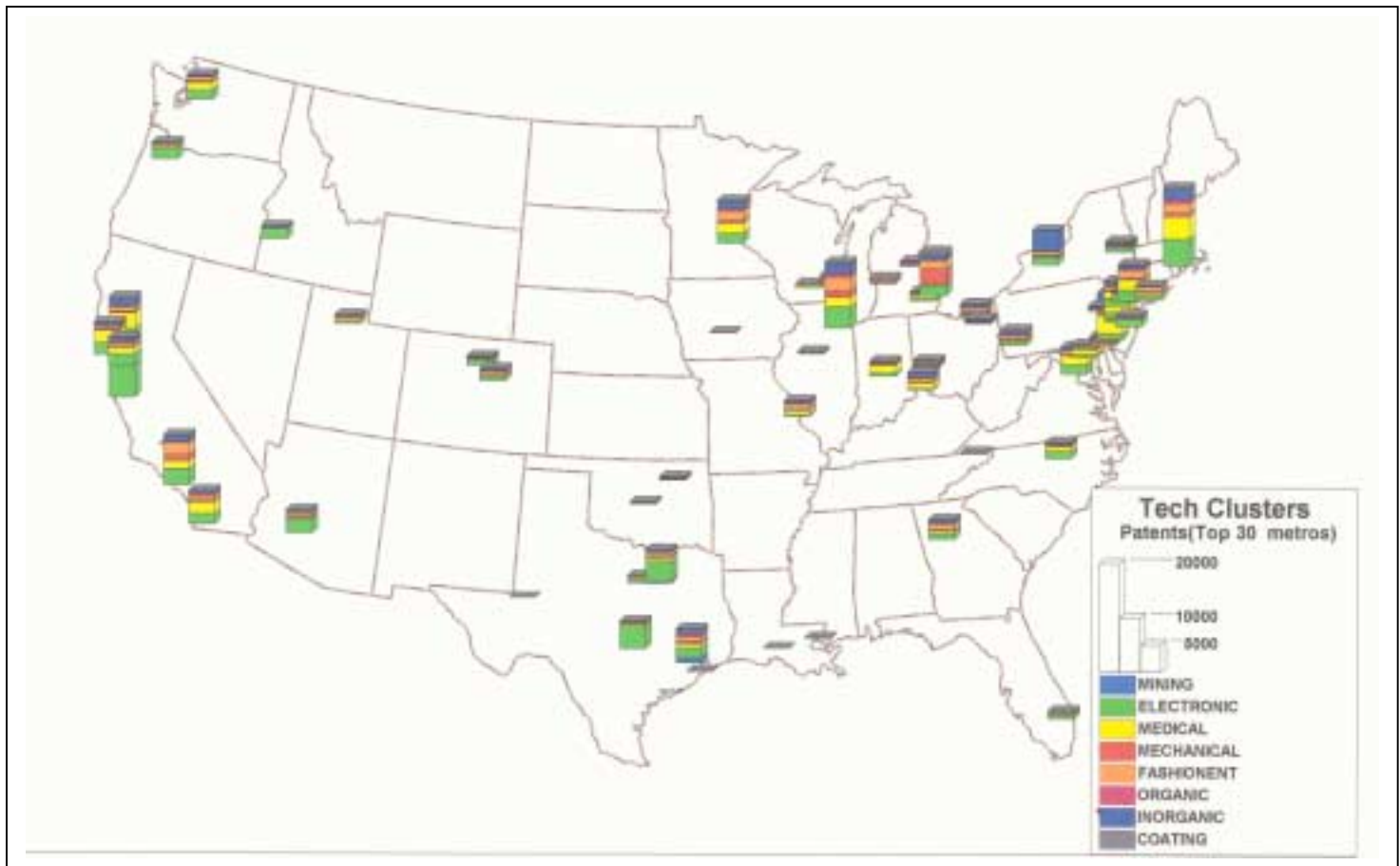
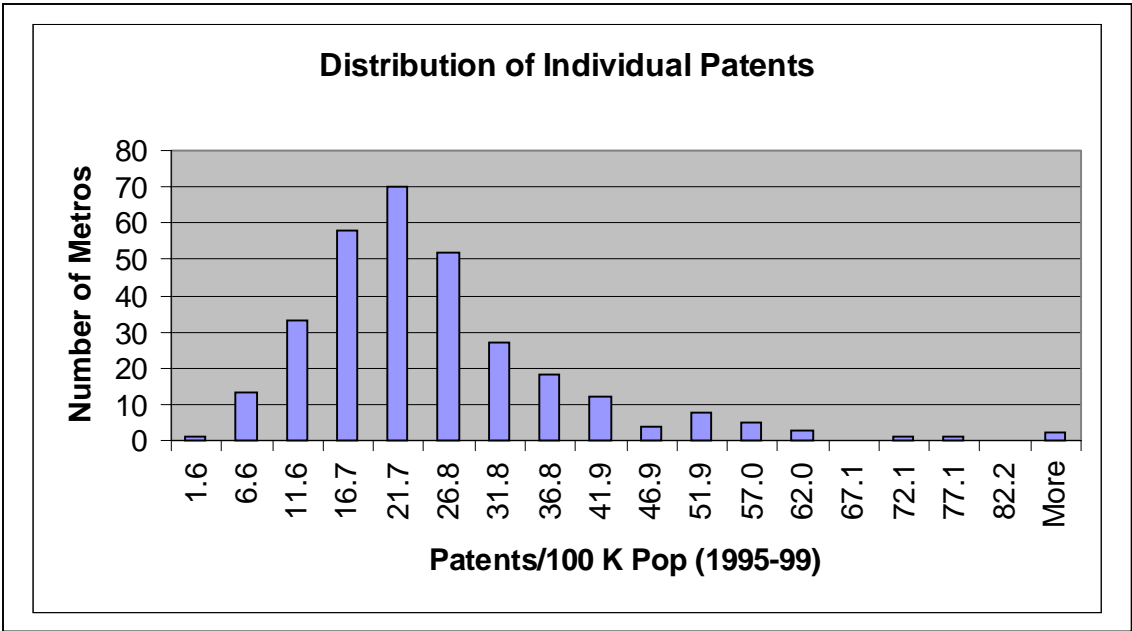


Table 3

US Patent Production

In 5 Years	Num. Of Companies	Patents	Percent
Over 100	641	300,232	55%
50-99	558	41,850	8%
25-49	1,036	38,850	7%
10-24	2,837	41,648	8%
5-9	4,985	37,388	7%
2-4	16,931	50,793	9%
1	33,353	33,353	6%
Total	60,341	544,114	100%

FIGURE 7



¹ Ross DeVol et al America's High Tech Economy: Growth, Development and Risks for Metropolitan Areas, 1999

² Sir Peter Hall *Cities in Civilization*, 1998

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⁴ Scott Stern, Michael Porter and Jeffrey Furman, The Determinants of National Innovative Capacity NBER Working Paper No. 7876 September 2000

⁵ Adam Jaffe "Real Effects of Academic Research" *American Economic Review*, December, 1989

⁶ J.P. Bouchard & M. Mezard, "Wealth condensation in a simple model of economy" *Physica A*, 282, p. 536 (2000) and Z. Burda "Wealth condensation in Pareto macroeconomics", *Physical Review E*, 65, #026201 (2002)

⁷ 252 entities in these 30 regions own a total of 357 research centers

⁸ Clayton Christensen, "The Rules of Innovation" *Technology Review* (June 2002), p. 33

⁹ A third of the 308 metros have rates above the national average and two-thirds fall below the mean.

¹⁰ Forbes ASAP, June 24, 2002 p. 84