High Tech Specialization: A Comparison of High Technology Centers

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"Contrary to common wisdom, high technology varies from place to place."

Findings

A comparative analysis of 14 "high tech" metropolitan areas found that high technology varies dramatically from place to place. Different metropolitan areas tend to specialize in relatively few products or technologies. This specialization can be seen in three measures: employment concentration, patent activity, and venture capital flows.

- **In most high tech regions, high tech employment is concentrated in only a few industry segments.** Metropolitan areas that show high concentrations of high tech employment in one technology, like software, will show very low concentrations in hardware (Washington D.C., Denver and Atlanta). Other regions show the opposite pattern: Phoenix is an employment center for hardware, but weak in software.

- **The majority of the patents issued in any given metropolitan area are granted to only a handful of firms specializing in one or more related technologies.** For example, San Jose, Phoenix, Portland and Austin show significant innovation in electronics or software technologies, and little activity in biomedical technologies. Washington D.C., Raleigh-Durham, San Diego, Boston and Seattle show significant innovation in biotechnology but produce fewer patents in electronics or software.

- **Venture capital flows not only to a few high tech metropolitan areas, but also to a specific set of technologies within those areas.** Venture capital in Boston flowed more to software and biotechnology. In Denver, investments were channeled into communications and computer storage firms. In San Diego, venture capital investments went disproportionately to medical industries.

I. Why High Tech Matters

Recent analytical studies have shown that technology businesses are playing an important role in driving the nation's economy, and they are especially potent contributors to the growth of regional economies. High technology businesses, particularly in software, computers and the Internet, are creating many new, high paying jobs, and transforming a wide range of traditional economic sectors. High technology is propelling the economy, growing four times faster than the overall economy in the 1990s.[2] Computers and information processing equipment accounted for over 40 percent of the growth in private, non-residential investment since 1995.[3] Information technology industries accounted for a third of U.S. economic growth between 1995 and 1999.[4]

For those metropolitan areas hosting significant concentrations of high technology industries, the beneficial impacts have been tremendous. Internet companies, software developers, biotech concerns, and computer and electronics companies pay high wages to programmers, scientists and engineers, and the computer and electronics companies have provided many opportunities for entry level jobs.

Moreover, the importance of high technology reaches beyond its role in triggering recent economic growth. High technology is also an "indicator species" of the process of growth in a knowledge-based economy. The key roles played by continuous innovation and "speed to market" in high technology today are increasingly coming to characterize the rest of the economy. In the years ahead, the process of development in all industries will more closely resemble the dynamics of high tech industries.

This survey presents a comparison of 14 metropolitan areas that are frequently counted among the nation's leading high technology centers: Atlanta, Austin, Boston, Denver, Minneapolis-St.Paul, Phoenix, Portland, Raleigh-Durham, Sacramento, Salt Lake City, San Diego, San Jose, Seattle, and Washington D.C.

In these metropolitan areas, per capita incomes were found to be somewhat higher than in other metropolitan areas, and incomes in these areas have been growing more rapidly than elsewhere. During the 1990s, employment in these metropolitan areas grew, in aggregate, about half again as fast as in the rest of the metropolitan U.S. (2.3 percent annually versus 1.6 percent annually). The disparity in manufacturing growth is even more striking: these 14 metropolitan areas grew by about 0.5 percent per year, while total U.S. metropolitan manufacturing employment declined 0.4 percent per year.[5]

But, while these 14 metropolitan areas may have commonalities, they also have important differences in their high tech economies. Contrary to common wisdom, high technology varies dramatically from place to place. Different metropolitan areas tend to specialize in certain technologies and have major concentrations of firms and employment in relatively few product categories. A few places, like Silicon Valley, excel in many areas. Most metropolitan areas, even those commonly labeled high technology centers, usually concentrate in relatively few products or technologies. A region that is strong in one area, say medical devices, doesn't necessarily have a competitive advantage in another area, like telecommunications, or semiconductors or software.

This survey probes the differences in high tech hot spots to enable us to better understand the dynamics of high technology development. It compares and ranks these 14 areas by a variety of indicators, including subsectors, employment concentration, venture capital investment and patent activity. It is important to point out that this survey does not attempt to produce an overall ranking of high tech hot spots, or a "top ten" list. Such a ranking implies that high tech regions are fundamentally similar, which is contradicted by our key finding: high tech regions differ from each other; some are strong in one area while others lead in another. This attention to the differences makes an overall ranking misleading. Building on the findings about high technology specialization, the study also offers recommendations for regional economic development strategies.

II. Methodology

We have selected metropolitan areas for comparison based on those most frequently mentioned in the popular literature. We have included the two most frequently studied centers of high technology (Silicon Valley and Route 128; the San Jose and Boston PMSAs, respectively); two smaller, but fast growing high tech centers (Austin and Raleigh-Durham), and several of the other mid-sized metropolitan areas in the West (Denver, Phoenix, Sacramento, Salt Lake City, San Diego, Seattle). We also included the Washington D.C., Minneapolis and Atlanta metropolitan areas. Our sample omits the nation's largest metropolitan areas (New York, Los Angeles, etc.), as we assume that different processes may be at work in these areas than in the more rapidly growing mid-sized metropolitan areas.

The style of analysis presented in this survey differs sharply from most academic and journalistic analyses of the location patterns of high technology industry. The general trend in such work is to develop a list of Standard Industrial Codes (SIC) thought to correspond with high technology processes or products, and then to simply aggregate data (employment, sales, value-added, investment) for all of the industries that meet the definition.

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While useful conceptually, it is not clear this kind of sweeping categorization is useful analytically. This binary classification of industries—an industry is either high technology or it isn't—implies that there is a great deal of homogeneity among these high tech firms. Statistical analyses—or rankings—that group inherently disparate firms such as medical devices, semiconductors, telecommunications and software together into a single category of "high technology", and attempt to explain their behavior as if they were homogenous units driven by a common set of factors, are likely to be substantially misleading and incomplete.

Recently, the federal government has adopted a new system for classifying industries: the North American Industry Classification System (NAICS). The NAICS makes a number of significant changes to the electronics, software and information industries. One extremely useful set of data, the 1997 Economic Census, has been released based on this classification system.

The SIC and NAICS codes selected for analysis in this study represent the core of the businesses creating hardware and software for information and communication technologies. Any classification system is, at best, an imperfect means of describing the activities of diverse and quickly changing business enterprises. Some firms in other industry classifications (for example, telecommunications service providers and research and development laboratories) play important roles in designing information technology. Businesses in nearly all industry classifications hire programmers and computer systems operators.

The details of data sources and analytical techniques are spelled out in the Appendix.

III. Findings

Each of the 14 metropolitan areas examined in this survey is a center for high technology industry, yet no two areas have identical mixes of industrial specializations, technological competencies or growth trajectories. With the exception of Silicon Valley (which seems to have an unusually broad range of technological competencies), the bulk of high technology employment in most areas is in firms that specialize in just a few technologies. For example, Denver has a particular strength in cable and telecommunications and a strong cluster of computer storage firms.
San Diego is a center for wireless communication and biotechnology. Salt Lake City specializes in medical devices and some kinds of software.

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Table 1: Principal Product Specializations

Region	Product Specializations
Atlanta	Databases, (Telecommunications)
Austin	Semiconductors, Computers, SME
Boston	Computers, Medical Devices, Software, (Biotechnology)
Denver	Data Storage, Telecommunications Equipment & Software
Minneapolis-St. Paul	Computers, Peripherals, Medical Devices
Phoenix	Semiconductors, (Aerospace)
Portland	Semiconductors, Display Technology, SME, EDA, Wafers
Raleigh-Durham	Computers, Databases, (Pharmaceuticals)
Sacramento	Computers, Semiconductors
Salt Lake City	Software, Medical Devices
San Diego	Communications Equipment, (Biotechnology)
San Jose	Semiconductors, Computers, Software, Communication Equipment, SME, EDA, Data Storage
Seattle	Software, (Biotechnology, Aerospace)
Washington D.C.	Databases, Internet Service, (Telecommunications, Biotechnology)

Note: SME: Semiconductor Manufacturing Equipment, EDA: Electronic Design Automation software. Specializations listed in parentheses are outside the definition of high technology used in this report, but, in some cases, are examined through analysis of patent activity.

Table 2: Estimated High Technology Employment, 1997

Region	Computer & Electronic Product Manufacturing	Software Publishers	Information Services & Data Processing Services	Computer Systems Design & Related Services	Total High Technology Employment
NAICS	334	5112	514	5415	
San Jose	166,578	22,708	3,768	19,195	**212,249**
Washington D.C.	20,014	9,839	20,942	87,867	**138,662**
Boston	71,715	25,211	11,355	25,464	**133,745**
Minneapolis	39,577	3,647	6,341	17,173	**66,738**
Atlanta*	17,436	6,922	*5,000 to 9,999*	25,979	**57,837**
Phoenix	43,743	2,616	3,054	6,638	**56,051**
Seattle	33,476	9,713	2,794	9,914	**55,897**
Austin	38,357	3,417	1,116	6,631	**49,521**
San Diego	30,825	4,483	3,199	8,789	**47,296**
Portland	32,924	5,302	1,496	5,433	**45,155**
Raleigh-Durham	30,191	1,858	1,174	6,930	**40,153**
Denver	8,938	2,966	5,839	15,545	**33,288**
Sacramento	14,385	2,064	3,904	3,640	**23,993**
Salt Lake	13,691	1,874	2,250	4,589	**22,404**

Source: Economic Census, 1997

Note: Exact data for NAICS 514 for Atlanta was suppressed by the Census Bureau to protect confidentiality; the actual total is between 5,000 and 9,999 employees. The mid-point of this interval (7,500) is used for computing Atlanta's total high technology employment (57,837).

Besides aerospace and avionics, Seattle is a center for software and biotechnology, and Washington D.C. specializes in databases and Internet services. Table 1 summarizes the specific product specializations for each of the subject metropolitan areas.[6]

High tech specialization manifests itself in three key indicators: employment patterns; patent activity; and venture capital flows:

A. In Most High Tech Metropolitan Areas, High Tech Employment Is Concentrated in Only a Few Industry Segments.

One standard way to measure the differences between various high tech sectors and judge their relative strengths and degrees of specialization is to compare their employment levels in high tech industries. Table 2 shows the total employment in computer and electronic manufacturing and a series of software and related industries in each subject metropolitan area in 1997. These data are reported using the new North American Industry Classification System (NAICS) industry coding system, which is replacing the long-used Standard Industrial Classification Code (SIC).[7]

It will surprise almost no one to learn that San Jose houses the largest concentration of high technology employees of any of the 14 metropolitan areas (212,249). Two other cities have large high tech complexes. Metropolitan Boston (133,745 high tech employees), home to Route 128, is a longtime center of computer and electronic manufacturing. Washington D.C. (138,662) also rates highly as a high technology employment center, largely because of the area's concentration of computer service and data processing firms, many serving government agencies. The other high technology centers have between 20,000 and 70,000 high tech employees.

Concentrations of high technology employment also illustrate the significant variation in technological specializations among metropolitan areas. Table 3 presents the location quotients of high technology employment for each area. Location quotients measure the concentration of employment, which reveals the relative specialization of an area in a particular industry; a location quotient of 1 means that employment in a particular industry represents the same share of total regional employment as it does in the national economy. A quotient greater than one means that a particular industry is more prevalent in a region's economy than in the nation's economy . For example, NAICS category 334, electronics and computers, makes up 14.13% of San Jose employment and 1.08% of U.S. employment, for a location quotient of 13.1 (14.13/1.08=13.08).

The location quotient is a critical measure of concentration and provides information that job numbers alone do not. As Table 2 shows, most of the metropolitan areas in this survey have, in terms of absolute job numbers, the highest employment in NAICS 334. However, they do not all specialize in

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Table 3: Location Quotients for Employment in High Technology Industries, 1997

Region	Computer & Electronic Product Manufacturing	Software Publishers	Information Services & Data Processing Services	Computer Systems Design & Related Services	Overall High Technology Location Quotient
NAICS	**334**	**5112**	**514**	**5415**	
San Jose	**13.1**	**11.3**	1.4	**3.3**	9.2
Austin	**4.9**	**2.8**	0.7	**1.9**	3.5
Raleigh-Durham	**3.7**	1.4	0.7	**1.9**	2.7
Washington D.C.	0.6	**1.8**	**3.0**	**5.7**	2.2
Boston	**2.2**	**4.8**	**1.6**	**1.7**	2.2
Portland	**2.6**	**2.7**	0.6	1.0	2.0
Seattle	**1.9**	**3.5**	0.8	1.2	1.7
Minneapolis	**1.8**	1.1	1.4	**1.8**	1.7
Phoenix	2.4	0.9	0.8	0.8	1.7
San Diego	1.8	**1.7**	0.9	1.2	1.6
Sacramento	1.5	1.4	**2.0**	0.9	1.4
Salt Lake	1.5	1.3	1.2	1.1	1.4
Denver	0.6	1.3	**1.9**	**2.3**	1.2
Atlanta	0.7	**1.7**	n/a	**2.2**	n/a

Source: Authors' calculations, Economic Census, 1997, Bureau of Economic Analysis

Note: Location Quotients greater than 1.5 shown in **bold**. Location quotients computed based on employment data. Because 1997 total employment for metropolitan areas was not available from the 1997 Economic Census, 1997 BEA Regional Economic Information Systems totals were used in computing location quotients. Because of data suppressions for NAICS 514 for Atlanta, location quotients were not computed.

that category. For example, Boston has more high tech manufacturing jobs than software publishing jobs, but, as Table 3 shows, it has a higher degree of concentration of, or specialization in, the latter.

Besides confirming the high tech credentials of the subject metropolitan areas (ten of the 13 areas for which location quotients could be computed were in excess of 1.5, meaning high tech made up half again as large a share of the local economy as the national economy), Table 3 illustrates that some regions are very strong in software, but weak in hardware (Washington D.C., Denver and Atlanta). Other regions show the opposite pattern: Phoenix is a center for hardware, but weak in software. Except for San Jose, Boston and Salt Lake City, each of these metropolitan areas has at least one high technology segment that represented a smaller share of its regional economy than of the national economy as a whole.

B. The Majority of the Patents Issued in Any Given Metropolitan Area Are Granted To Only a Handful of Firms, Specializing in One or More Related Technologies.

A hallmark of high technology industries is their continual development of new products and processes. One rough measure of the innovative activity in a metropolitan area is the number of patents awarded to firms, individuals and research institutions in that area. Collectively, patent activity in the high technology metropolitan areas is dramatically greater than elsewhere, and is increasing much more rapidly. Overall, the average rate of patenting in the selected metropolitan areas is about twice as high (per manufacturing employee) as it is for the entire metropolitan population of the United States (See Table 4). Only Atlanta had a lower-than-national-average patent rate. U.S. metropolitan areas as a whole average about 38 patents per ten thousand manufacturing workers annually; the subject metropolitan areas averaged more than 62 patents per ten thousand workers. Patent activity is also growing faster in these 14 areas than in all of the metropolitan U.S.: 11 percent annually versus about 7 percent annually. The exception is Denver, which had a slower-than-national-average rate of patent growth between 1990 and 1998.

Among the 14 metropolitan areas studied, patent rates varied by a factor of four, from about 120 patents per ten thousand manufacturing workers in San Jose to about 30 patents per ten thousand manufacturing workers in Atlanta.[8]

Patent data also seem to confirm the heterogeneity of high technology in the metropolitan areas we examined. Not only do patent rates vary substantially among the metropolitan areas studied, but the focus of patent activity varied as well. Frequently, a majority of the patents issued in any given metropolitan area are granted to

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Table 4: Total Patents Issued and Patent Intensity, 1990 and 1998

Metropolitan Area	1990	1998	1990–98 Growth Rate	Patent Rate
San Jose	1,295	4,931	16.7%	121.7
Austin	354	1,440	17.5%	110.9
San Diego	761	1,673	9.8%	92.6
Washington D.C.	755	1,292	6.7%	88.4
Raleigh-Durham	233	828	15.8%	59.7
Boston	2,051	3,687	7.3%	57.8
Minneapolis	1,154	2,051	7.2%	54.9
Salt Lake City	236	472	8.7%	50.1
Phoenix	493	1,182	10.9%	47.5
Sacramento	121	289	10.9%	45.4
Denver	346	581	6.5%	43.9
Seattle	573	1,275	10.0%	42.0
Portland	384	948	11.3%	42.3
Atlanta	461	1,034	10.1%	32.7
These 14 Metropolitan Areas	9,217	21,683	10.7%	62.8
Totals for All U.S. Metro Areas	43,637	74,714	6.7%	38.2

Source: U.S. Patent & Trademark Office, 1999

Note: Growth rate is average annual growth rate in patents. Patent rate is 1997 utility patents issued per 10,000 manufacturing employees.

only a handful of firms specializing in one or more related technologies.

We also computed location quotients—which, again, are important measures of concentration that reveal trends that absolute numbers can mask—for several of the most important classes of computer hardware and software. For comparative purposes, location quotients were also computed for two categories of biomedical technology. The data presented in Table 5 show considerable variation in the technological specializations of metropolitan areas. Except for San Jose, none of the metropolitan areas show strong specializations (location quotients in excess of 1.5) in all four of the electronics and software related technologies. The areas that are strongest in these technologies (San Jose, Phoenix, Portland and Austin) tend to be relatively least specialized in biomedical technologies. Conversely, the areas with the most emphasis on biotechnology (Washington D.C., Raleigh-Durham, San Diego, Boston and Seattle) have fewer strong specializations in electronics. Atlanta, Denver, Minneapolis and Salt Lake City have no significant specializations in these particular technologies, even though they have significant high technology employment.

C. Venture Capital Flows Not Only to a Few High Tech Metropolitan Areas, but Also to a Specific Set of Technologies Within Those Areas.
The 14 high technology metropolitan areas in this survey accounted for approximately 46 percent of the number of venture capital investments made in United States between 1995 and 1999 (See Table 6). Because venture capital drives the creation of new enterprises and the growth of high tech employment, it tends to accentuate existing technological differences among metropolitan areas. Metropolitan specialization appears to be reflected (and perhaps amplified) by geographical concentrations of venture capital. Capital, often pictured as the most mobile factor of production, in fact shows a strong tendency toward localization. Venture capitalists in a particular region tend to specialize in investing in the set of technologies that are most concentrated in their home region, even when they make investments in other metropolitan areas.[9]

Data showing the number of venture capital investments made in the last four years in the subject metropolitan areas are presented in Table 6. Venture capital investments are highly concentrated in a relatively few metropolitan areas. According to one study, more than 60 percent of all venture capital flowed to just five metropolitan areas—San Francisco, Boston, New York, Los Angeles and Washington D.C.[10] San Jose and Boston got more venture capital investments than the other 12 cities in the survey combined.

Like productive activity, venture capital tends to have pronounced

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Table 5: Location Quotients for Selected Technologies, 1994-98 Patents

Technology	Electronics and Software Technologies			Biomedical Technologies		
Patent Class	Class 345	Class 364	Class 395	Class 438	Class 435	Class 514
Class Description	Computer Graphics Processing *	Electrical Computers and Data Processing	Information Processing System Organization	Semiconductor Device Manufacturing Process	Chemistry: Molecular Biology and Microbiology	Drug, Bio-Affecting and Body Treating Compositions
Atlanta	0.5	0.4	0.4	0.1	0.8	0.5
Austin	**4.1**	**4.5**	**7.6**	**6.3**	0.3	0.2
Boston	1.2	0.9	**1.8**	0.5	**2.3**	1.3
Denver	0.4	0.7	0.6	0.7	1.0	0.6
Minneapolis	0.3	0.9	0.5	0.3	0.4	0.2
Phoenix	1.5	**1.8**	1.4	**4.5**	0.1	0.2
Portland	**3.9**	**2.2**	**4.9**	1.2	0.5	0.2
Raleigh-Durham	**1.7**	1.4	**2.0**	0.7	**3.2**	**2.1**
Sacramento	0.5	1.0	**3.4**	0.4	0.2	0.2
Salt Lake	1.3	0.5	0.3	0.0	1.2	0.7
San Diego	1.1	0.8	0.6	0.5	**3.5**	**1.9**
San Jose	**3.4**	**3.2**	**3.6**	**3.8**	0.8	0.4
Seattle	**4.5**	0.9	**2.3**	0.1	**2.2**	1.0
Washington D.C.	0.8	0.2	0.7	0.3	**3.3**	**2.7**

Source: Authors calculations, U.S. Patent and Trademark Office, 1999
Location Quotients greater than 1.5 shown in **bold**.
* - Complete class description is Computer Graphics Processing, Operator Interface Processing, and Selective Visual Display Systems.

regional specializations: Table 7 displays location quotients—a measure of specialization—for five of the metropolitan areas included in the survey.[11] In the five metropolitan areas included in Table 7, venture capital flows to a specific set of technologies. While venture capital in Boston flowed more to software and biotechnology, in Denver investments were channeled into communications and computer firms. In San Diego venture capital investments flowed disproportionately to the area's medical and biotech industries.

VI. Policy Implications

Looking in detail at the specialties of the leading high technology firms in 14 metropolitan areas provides a variegated picture. The strong and consistent role of specialization in shaping the pace and character of metropolitan high tech development

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Table 6: Venture Capital Investments, 1995 to 1999

Metropolitan Area	Number of Investments	Share of U.S. Venture Capital Investments	Share of 14 Metropolitan Area Venture Capital Investments
San Jose	1,518	15.2%	32.8%
Boston	1,048	10.5%	22.7%
San Diego	326	3.3%	7.1%
Seattle	283	2.8%	6.1%
Washington D.C.	249	2.3%	5.4%
Atlanta	240	2.4%	5.2%
Minneapolis	215	2.2%	4.7%
Raleigh-Durham	179	1.8%	3.9%
Denver	172	1.7%	3.7%
Austin	168	1.7%	3.6%
Phoenix	84	0.8%	1.8%
Portland	78	0.8%	1.7%
Salt Lake City	45	0.5%	1.0%
Sacramento	17	0.2%	0.4%
Total	**4,622**	**46.2%**	**100.0%**

Source: Zook, 1999
Note: Percent of total is the share of all U.S. venture capital investments made between 1995 and 1999.

Table 7: Location Quotients for Venture Capital Investments in Selected Metropolitan Areas, by Industry Segment, 1996 to 1999

Industry	San Francisco	Boston	Denver	Seattle	San Diego
Communications	1.0	0.9	**2.0**	**1.2**	0.7
Computers & Peripherals	**2.0**	0.4	**1.5**	0.1	0.4
Electronics & Instrumentation	**1.3**	0.6	0.9	-	**1.4**
Medical Instruments/Devices	1.1	1.2	0.0	0.0	**5.3**
Semiconductors & Equipment	**2.6**	0.9	-	-	-
Software & Information	**1.4**	**1.2**	0.6	**1.3**	0.5
Biotechnology	0.8	**1.6**	0.9	**1.3**	**4.8**

Source: Zook, 1999

Note: Numbers shown in **bold** represent industries with a location quotient greater than 1.10. San Francisco is the San Francisco Bay Area, including San Francisco, Oakland and San Jose.

underscores the fundamentally indigenous and idiosyncratic nature of development. In thinking about strategies for developing a high tech economy, the leaders of any metropolitan area are well advised to look closely at their own existing knowledge base for the best opportunities to grow an industry cluster.

The tendency toward high tech specialization suggests that decision makers should avoid replicating generic development strategies. Because high technology is so diverse, and because it prospers in response to the distinctive knowledge base and characteristics of each individual region, there is no universal recipe for high technology success.

The survey findings also underscore the difficulty of generating a new high technology cluster where none previously existed. Because new high tech clusters build on the knowledge base of current workers and firms, metropolitan areas with weak technological endowments are greatly handicapped in creating new ones. Successful high technology development is usually an indigenous process, building most critically on the distinctive knowledge and existing industrial base of a region. Moreover, prowess in one high tech field doesn't necessarily qualify an area to succeed in others. Economic development efforts should be tailored to build on or extend existing strengths or emerging local competence; trying to create a totally new high tech center where none currently exists is likely to be a lengthy, and probably fruitless, endeavor.

Even metropolitan areas with current strengths in high technology are not guaranteed the opportunity to succeed or even compete in every emerging industry segment. The existing knowledge base likely constrains future development opportunities. Being strong in mainframe computers may be of little advantage in biotechnology; being strong in biotechnology may not produce any advantage in electronic commerce, even though all of these industries are recognized as "high tech."

Historical lock-in to a particular technology can be either good or bad. Surging demand for a hitherto modestly exploited technology (like wireless communication or the Internet) can trigger phenomenal growth in those metropolitan areas with substantial competence in that area (for example, Qualcomm and Sony in San Diego, and America On-Line, MCI and Network Solutions in Washington D.C.). Likewise, being locked into a declining technology, or one jeopardized by aggressive competitors, can be a regional disaster. The rise of micro-computers in the 1980s, which triggered growth for the technologically well-positioned firms of Silicon Valley (including Apple, Intel and others), undermined the fortunes of Boston's Route 128 (the nation's center for manufacturers of mini-computers, including DEC, Wang and Data General), and Minneapolis (home of mainframe manufacturers including Control Data, Honeywell and Unisys).[12]

Given the enormous and inherent heterogeneity in high tech products and processes, there should be little surprise that there isn't any single cause that triggers the development of high tech clusters. Despite similarities in industrial classification, occupational composition and research intensity, the sheer variety of specializations among metro areas, and their persistence over time, suggests that researchers and civic leaders should pay close attention to the diversity and evolution of high technology.

Note: Individual regional summaries for each of the 14 "high tech" metropolitan areas are available on the Brookings Institution website: www.brookings.edu/urban.

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Appendix: Methodology

This study is a cross sectional comparison of the demographics, industrial structure and knowledge base of a series of selected metropolitan areas. Our methodology has been to choose a series of mid-sized regions, assemble basic demographic data about each, measure the overall size of the electronics, instruments and software industry in each, identify the largest local employers and their specializations and to examine the major sources of patent activity in each metropolitan area.[13]

A. Selection of Metropolitan Areas

As noted in the text, we have selected metropolitan areas for comparison based on those most frequently mentioned in the popular literature. We have included the two most frequently studied centers of high technology (Silicon Valley and Route 128; the San Jose and Boston PMSAs, respectively); two smaller, but fast growing high tech centers (Austin and Raleigh-Durham), and several of the other mid-sized metropolitan areas in the West (Denver, Phoenix, Sacramento, Salt Lake City, San Diego, Seattle). We also included the Washington D.C., Minneapolis and Atlanta metropolitan areas. Our sample omits many of the nation's largest metropolitan areas (New York, Los Angeles, etc), as we assume that different processes may be at work in these areas than in the more rapidly growing mid-sized metro areas. As much as possible we have attempted to obtain and display data for the entire metropolitan area for each case study. Eight of our 14 cities were on Fortune magazine's list of Ten Best Cities for Business in 1998 (Austin, Salt Lake City, Phoenix, San Jose, Raleigh-Durham, Portland, Atlanta, and Denver).

B. High Technology Definition

We define high technology as the computer, electronics, instruments and software industries, a definition drawn from our study of the high technology industry in the Portland metropolitan area. We used Standard Industrial Classification codes to analyze employment data and to classify firm level information. We restricted our analysis to two-digit and three-digit codes to maximize the availability of data. Included codes were as follows:

SIC 357:	Electronic Computers
SIC 36:	Electrical Machinery
SIC 38:	Instruments
SIC 737:	Software and Data Processing Services

Recently, the federal government has adopted a new system for classifying industries: the North American Industry Classification System (NAICS). The NAICS makes a number of significant changes to the electronics, software and information industries. One extremely useful set of data, the 1997 Economic Census, has been released based on this classification system. To make use of these data, we selected in the principal NAICS categories corresponding to our SIC code definition of high technology. Included codes were the following:

NAICS 334:	Computer and Electronic Product Manufacturing
NAICS 5112:	Software Publishers
NAICS 514:	Information and Data Processing Services
NAICS 5415:	Computer Systems Design and Related Services

These NAICS definitions correspond closely to the SIC code definitions we used. Based on bridge tables published by the U.S. Census Bureau for 1997, 98 percent of the employment in the selected NAICS codes was previously classified in one of our four selected SIC codes.[14] Conversely, about 75 percent of the employment in our SIC code categories was in one of the selected NAICS codes. Based on 1997 Census data, about 4 million persons worked in high technology industries as defined by our four SIC categories; about 3 million worked in the selected four NAICS categories.

The SIC and NAICS codes selected for analysis in this study represent the core of the businesses creating hardware and software for information and communication technologies. Any classification system is, at best, an imperfect means of describing the activities of diverse and quickly changing business enterprises. Some firms in other industry classifications (for example, telecommunications service providers and research and development laboratories) play important roles in designing information technology. Businesses in nearly all industry classifications hire programmers and computer systems operators.

Our definition of the high technology industry differs from that used in some other studies. Other definitions of high technology focus on the research and development intensity or occupational composition of certain industries, assigning groups of SIC codes to "high technology" if they have relatively large research and development expenditures or relatively large fractions of workers who are scientists or engineers. Our definition is more closely aligned with an industry cluster, looking at groups of firms that share similar labor force demands, technologies, and markets, and for which there are likely to be significant buyer-supplier relationships. This definition is similar to that developed by the American Electronics Association for its analysis of

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High Technology Definitions Used by Various Studies

SIC Code	Industry Description	Markusen	Saxenian	DeVol	Oregon
28	Chemicals & Pharmaceuticals	All		Part	
30	Rubber & Plastics	Part			
34	Fabricated Metals	Part			
35	Industrial Machinery	Part			
357	Computers	All	All	All	All
36	Electrical Equipment	Part	Part	Part	All
37	Transportation Equipment	Part	Part	Part	
38	Instruments	Part	Part	Part	All
481	Telephone Communication Services		All	All	
737	Software & Data Processing		All	All	All
87	Engineering & Management Services			Part	

Sources: Methodology reported by Markusen, Hall et al. 1986, Saxenian 1994, DeVol 1999. Oregon is the Oregon Employment Department.
Note: "All" means all subsidiary SIC codes in the two or three digit category are included in the definition of high technology; "Part" means only some of the subsidiary SIC codes are considered high technology.

CyberStates; it differs from the AEA definition in that it excludes telecommunications services (SIC 48).[15] Most telecommunications employment in the United States involves service provision for local markets, including infrastructure maintenance, switch operation, customer service, billing and the like. We have highlighted the role of telecommunications in two metropolitan areas—Denver and Washington D.C.—where telecommunications firms are heavily engaged in research, development and headquarters activities.

In general we exclude biotechnology from our statistical analysis of high technology. Biotechnology activities span a number of Standard Industrial Classification codes (including pharmaceuticals, chemicals, research and development, medical laboratories, hospitals, and universities). In addition, biotechnology is generally recognized as involving different sets of skills, technology and science than electronics and software. We have included some information about biotechnology for those metropolitan areas where there appears to be a significant biotechnology or biomedical cluster as indicated by patent data.

Academic studies that have analyzed the geographic location patterns of high technology industry frequently classify firms as high technology based on the average intensity of industry-wide research and development spending or on an industry's relative concentration of certain broad occupational groups (scientists, engineers and technicians).[16] Arguably, these approaches identify groups of industries that use higher levels of technology than the average firm in their production processes.

The implication of these studies is that high tech industries as a group are similar to one another and different from all other industries in not only their identifying characteristics, but also in their locational processes and preferences. But as Porter's detailed analyses of geographic clusters around the world makes clear, firms (and regions) tend to specialize in product niches that are much narrower than the broad amalgams of 3 digit SIC codes that are almost always used to define high technology. As a result, clusters rarely conform to standard industrial classification systems:

> The view that there are different explanations for international success that apply to different industries has led some authors to divide industries into groups such as traditional, knowledge intensive, resource intensive, scale or mass production sensitive, and high technology (or science-based). . . . The aim of such categories is to reflect the varying determinants of competitive success in different industries. The problem with such generalizations is that technological change and the globalization of strategy have blurred the categories. . . . No simple division of industries can capture the diversity of sources of competitive advantage and how they are achieved.[17]

Any definition that relies on groups of Standard Industrial Classification codes is likely to only roughly capture the product and market specializations of the firms and areas being analyzed. At the two and three digit level, there is still considerable variety in the outputs, technologies and scale of individual firms. Where possible, we have attempted to more precisely characterize the specializations of each metropolitan area by looking at firm level information. In some cases we have included firms that are not primarily classified as part of one of the four two and three digit industry groups listed above. For example, in our analysis of the Denver metropolitan area, we identified a high concentration of telecommunications firms, which in addition to providing services to customers also had substantial research and development activities in Denver. Because these telecommunications, satellite and cable

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firms are headquartered in this area and develop new technologies there (incorporating electronics and software) we included them in our discussion of the high technology industry in Denver.

C. Aggregate Data

To benchmark the overall size and recent economic performance of each of these metropolitan areas, we have assembled data on overall population growth, employment, numbers of manufacturing jobs and other key characteristics of these areas. This data is drawn from estimates prepared by the Bureau of Economic Analysis and the Census Bureau, as well as selected commercial data sources.

We relied heavily on the recently published data from the 1997 Economic Census.[18] This Census is the first major data series to employ the new North American Industry Classification System (NAICS). A new subsector (NAICS 334), combines computers, high tech electronics and instruments, categories previously separated in the SIC, and consequently subject to data suppression at the level of individual metropolitan areas. The Economic Census contains publishable data on employment for NAICS 334 for all the metropolitan areas in our study.

We also examined data from two other sources in our effort to construct metropolitan area comparisons. The Census Bureau and the Bureau of Labor Statistics publish estimates of the number of establishments, employment and payrolls by metropolitan area. Data collected from federal tax records is published in County Business Patterns.[19] The Bureau of Labor Statistics publishes Covered Employment and Payroll from data collected by state employment security agencies. The utility of both of these data sources is limited by the agency's suppression of certain data for SIC categories in metropolitan areas where one or a few firms account for nearly all employment. Our analysis of these data are summarized in our study, "A Comparison of High Tech Centers, Regional Connections Working Paper 4" available at http://www.upa.pdx.edu/IMS/.

While 14 observations is too small a sample for reliable statistical analysis, it is useful to look at the quantitative relationship between various aspects of high technology. We used the 1997 Economic Census data on high technology employment to examine the correlation between employment in one high technology industry and others. We measured the correlation coefficients among the four major component sectors of NAICS subsector 334 Computer and Electronic Product Manufacturing: computers and peripherals, communication equipment, semiconductors, and instruments. Our analysis showed that there was some correlation (correlation coefficient ranging from .33 to .84 and averaging .62) for the full sample of metropolitan areas. These correlations, however, are due largely to the dominant role of San Jose, which is large, and well represented in all segments of high tech. The correlation coefficient excluding San Jose, however, was very low (averaging .16, and ranging from -.10 to .43). For example, while there was some correlation between employment in manufacturing instruments and communications equipment, there was actually a negative correlation between semiconductors and computers. Thus, for the bulk of high tech centers, there is very little correlation between prowess in one area and prowess in another. Outside Silicon Valley, high tech is very specialized.

Employment data reported by industrial classification has another flaw, one that is frequently ignored in data analysis. While firms may undertake activities and produce products and services that span a variety of industry codes, as a rule, employment at the establishment level is classified according to a single industry code. Firms, particularly large firms, often combine a variety of functions and activities in a single location. In many cases the characteristics of these activities vary greatly in their pay levels, technical complexity, and substance. For example, a telecommunications company might include the development of software or services at a location that also provides communication services. Similarly, a semiconductor manufacturer may also produce software. Many computer firms operate large customer support call centers, whose personnel are aggregated with manufacturing employees if they are housed in the same establishment.

D. Firm Level Data

Most economic studies of high technology industry rely on aggregate data, such as employment totals for groups of firms in broad industry categories. Often such data conceals the structure and dynamics of high tech clusters and the role of leading firms. Increasingly, researchers are looking to supplement aggregate data with firm-level information.[20] We attempted to identify, by name, the largest high technology firms in each of the metropolitan areas we studied. While the statistical data published by public agencies seldom identifies individual firms (to protect confidentiality), private data sources regularly attempt to name names. The American City Business Journals, a national chain of weekly business newspapers, regularly publishes lists of firms in specific industry categories in each of its markets, typically coinciding with metropolitan statistical agencies. Typical lists include largest local employers, largest public and private firms, and largest high technology or electronics employers in a region. These lists are compiled by researchers for the newspapers, typically by calling individual firms to verify pertinent information. While coverage is seldom complete, and definitions for particular data fields are not as rigorous as those produced by statistical agencies, these lists represent good pictures of the larger firms in any given metro area.

We supplemented in the information contained in the American City Business Journals' lists with other data. For example, we utilized the Corp Tech database and the Thomas Register, to obtain additional information about the products and industrial classification of certain firms. In

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addition, we consulted other sources, including trade associations, universities and public development agencies in the subject metropolitan areas to obtain additional information and to provide a top employer list for Salt Lake City, where the American City Business Journals did not have a local affiliate. In two cases, Denver and Washington D.C., we were not able to obtain or construct lists of high technology firms that were fully comparable to the lists available for other metropolitan areas. In both cases, telecommunication service providers (Internet, wireless, telephone cable, and satellite) are major local employers. These telecommunications firms embrace a mix of high tech (research, development and manufacturing functions) and low tech (service provision, customer support, billing), but are aggregated in into a single industry code or firm level listing of employment totals.

A key characteristic of the high technology industry is the continuous and rapid creation of new products and new production processes. We attempted to analyze the relative importance of knowledge creation in high tech industries by examining patent data. The U.S. Patent and Trademark Office produces several statistical series summarizing patenting activity, including tabulations of the number of patents issued by metropolitan area and by firm. For our analysis, we examined both the overall number of patents issued in each subject metropolitan area, and the number of patents issued to private high technology firms in each metro area. (We are grateful to Bill Brown at the patent office for helping us obtain and tabulate this data).

The availability of equity capital to finance the start-up costs of new firms is frequently cited as an important ingredient in the growth of high technology industries. A number of private financial firms track venture capital investing throughout the nation. We present some limited data tabulated by Pricewaterhouse Coopers and by Matthew Zook detailing the regional distribution of venture capital investments in the United States in recent years.

Endnotes

1 Joseph Cortright is an economist with Impresa, Inc., and principal investigator for the New Economy Observatory of Portland State University's Institute for Portland Metropolitan Studies. Heike Mayer is a graduate research assistant with the Observatory and Ph.D. candidate in the University's College of Urban and Public Affairs.

This abstract draws on research the authors undertook as part of their study of high technology in the Portland metropolitan area entitled *The Ecology of the Silicon Forest.* For a complete copy of their report, including data and profiles of individual metropolitan areas, visit the Regional Connections website at www.upa.pdx.edu/IMS/

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6 Product specializations listed in Table 1 differ from the industry categories shown in Tables 2 and 3 because neither the SIC nor NAICS classification systems precisely align with the ever-changing boundaries of commercial markets. Some product specializations represent small parts of large industry categories—for example, Electronic Design Automation (EDA) software used to design circuitry—the data for which are seldom available for individual metropolitan areas. In other cases, a single set of closely related products might be classified in many different industry categories—semiconductor manufacturing equipment (used to fabricate chips, using chemicals, light and electricity) includes, for example, electrical and non-electrical machinery and instruments, all part of different SIC code industries.

7 NAICS subsector 334, computer and electronic manufacturing, corresponds closely to the old SIC categories for computers (SIC 357), high technology electronics such as communications equipment and semiconductors (SIC 36) and the non-medical portion of instruments (SIC 37). The three listed software, information and computer design services NAICS industries correspond to SIC 737, software and data processing services.

8 Manufacturing employment seems like a plausible factor for adjusting gross patent counts because a large fraction of patents are issued for technologies used to manufacture goods, and the largest private sector patent holders in almost every metropolitan area are manufacturing firms.

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