The Ecology of the Silicon Forest

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During the past decade, metropolitan Portland has emerged as one of the nation's fastest growing high technology centers. The region differs significantly from other metropolitan high tech centers in its industry specializations. The cluster of high tech firms that compose Portland's Silicon Forest specialize in semiconductors, chip production equipment and software, printers, displays, and software. Creating new knowledge, as evidenced by research and development, patenting, and rising educational attainment, is closely related to the growth of the industry. While the region's specializations have evolved over time they are clearly rooted in technological competences established in the region decades ago. This continuing evolution is fueled by the local business culture and supporting institutions like venture capital. Within the metropolitan area, high tech firms are tightly clustered in proximity both to one another and the region's high tech labor force. An ecological metaphor, the interdependent and evolving Silicon Forest, usefully describes many of these processes at work in the development of metropolitan Portland's high technology industry.

Seeing a new landscape

In Oregon we're used to seeing the connections between the land and the economy. Early settlers came to the Willamette Valley because they could see in its fertile soils, abundant rivers, and verdant forests a clear landscape of economic opportunity. This place was rich and desirable because of these unique characteristics. Even today, battles over forest management, salmon restoration, and other natural resource issues are understood to be vital to the economy because of the connections between the natural landscape and the economy.

Today, however, there is another landscape, less easily seen, but equally important to our economic well being. Underlying the new economy is a knowledge landscape composed of the skills and insights imbedded in the hundreds of thousands of workers in the region and the region's firms. This knowledge landscape is as varied and distinctive from place to place as the geology, the climate, or the vegetation. The knowledge strengths that exist here, like the temperate old growth forests, exist in few other places on earth.

In crucial ways, the knowledge landscape is wedded to the physical landscape and to our communities. People and businesses want to remain here because of the region's outstanding quality of life. However, this attractiveness is only part of the story. The critical mass of intellectual talent, innovative firms, a business culture that encourages entrepreneurship, and key institutions that support the formation and growth of new firms make it possible for successive generations of technology and business to develop in this area.

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The contours of the knowledge landscape are apparent in the development of metropolitan Portland's high technology industry cluster. Half a century ago the region had no technology related industry of any national or even regional consequence. Portland was a sleepy little commercial center in a natural resource economy. Much has changed since then. To understand these changes, and to see their connection to the knowledge economy, this paper makes six major points. First, we establish some context, offering a brief description of the regional economy. Second, we measure the overall dimensions and recent growth of the region's high technology sector, focusing in particular on its technological specialties. Third, we consider the reasons for the development of high technology in the Portland area. Fourth, we suggest that the region's high tech sector has emerged and continues to develop as part of a dynamic, evolutionary process. In that light, we look in the fifth part of the paper at the history of the Silicon Forest, tracing the key events that have driven the region's evolution. Sixth, we consider the geography of the high technology cluster and provide more evidence based on the different location patterns of high tech firms on the dynamics of regional growth.

I. The Portland Metropolitan Economy in the 1990s

The Portland metropolitan economy has compiled an impressive performance record during the 1990s. The region has added more than 200,000 new jobs during the decade, seen its per capita income rebound from slightly less than the national average to more than 8 percent above the US average, and also seen its unemployment rate decline to 30 year lows.

The federally designated Portland-Vancouver standard metropolitan area consists of six counties, Clackamas, Columbia, Multnomah, Washington, and Yamhill in Oregon, and Clark County Washington. As of 1999, the region has nearly 1.8 million residents and more than a million workers. The region has more than 50,000 businesses with a payroll and a gross regional product of more than $60 billion. Portland/Vancouver is the 27th most populous metropolitan area in the nation, but ranks 10th in export volume and 20th in number of manufacturing jobs. During the 1990s, there has been considerable in-migration of new residents and these new residents have tended to have much higher than average levels of education than the current population.

The region's economic base is composed of a number of major industry clusters—groups of closely related firms producing similar products, and their specialized suppliers. Metropolitan Portland's traded sector industry clusters are marked by above average concentrations of employment in high technology, metals/machinery/transportation equipment, wood products, creative services, and nursery products. Portland area businesses in each of these clusters have outperformed their counterparts in the rest of the nation. The region is also a major center for wholesaling activity. This category includes some corporate headquarters, such as Nike, and many producer services related to other clusters including engineering support and manufacturers representatives serving the high tech industry.

In particular, explosive growth in the high technology cluster has been the leading cause of the region's strong economic performance during the 1990s. High technology—defined as electronics, computers, instruments, and software—is the largest of the region's traded sectors. During the early 1990s, the region's high technology employment increased at a time when it was declining nationally; in the mid-1990s, metro Portland's growth has significantly outpaced that of the nation. Understanding the forces driving this cluster is the key to unlocking the process of growth in the region.

II. Dimensions of the Silicon Forest

The Silicon Forest is the name given to the cluster of electronics and related businesses in the Portland area. Over the past decade, the metropolitan area has emerged as a significant national center for the production of a variety of high technology products and services. The Silicon Forest consists of more than 2,000 firms producing semiconductors, computers, electronic products, and computer software, and a wide array of related and supporting industries. While larger firms like Intel and Tektronix are well known the region is also home to hundreds of smaller firms that sell their products worldwide.

More than 70,000 persons are employed by high technology businesses in the Silicon Forest. In excess of 30,000 of these jobs have been added during the decade of the 1990s. The pay for these employees is high. In fact, the average pay in electronics and software firms is more than $50,000 annually—about two-thirds higher than the average for all jobs in the region.

Taken as a group, Portland's high technology firms have significantly outperformed the US high tech industry. Overall, Silicon Forest businesses have grown about three times faster over the past five years than their counterparts nationally--more than eight percent per year compared with about 2.6 percent per year for the nation.

The region's particular slice of high tech industries is not a random cross section of U.S. high technology. Silicon Forest firms have distinctive specialties. Portland is an important center for microprocessor design, silicon wafer making, wafer fabrication, semiconductor test and measurement equipment, electronic design automation (EDA) software, display technology, and high frequency, mixed signal integrated circuits.

The environment that favored the growth of the Silicon Forest in the 1990s was created in large part by the phenomenal success of homegrown Tektronix, which accounted for a majority of Oregon's high tech production in the 1960s and 1970s. Investments and subsequent expansions by Intel and Hewlett Packard in the late 1970s, as well as a wave of Japanese investment in the 1980s, stimulated further industry growth. More recently, in the mid 1990s, Intel and several other firms announced plans to invest about $10 billion in new semiconductor production capacity in the metropolitan area. Additionally, throughout the 1980s and 1990s, new start-up firms, many of them spin-offs of the ideas,

expertise, and personnel of the region's larger firms, fueled the expansion of the Silicon Forest.

The indirect and multiplier impacts from the purchases and re-spending of income by high tech firms, their suppliers, and employees has been the primary force in the region's growth in the 1990s. High tech firms have a total payroll in excess of $3.5 billion. The multiplier effects of this spending push its total economic impact in the regional economy to a total of more than $5 billion.

III. Why is there a Silicon Forest?

A number of explanations have emerged in the past decade about the reasons for the emergence of high technology in the Portland area. One variant, the conventional wisdom, holds that Portland, a short plane ride away from Silicon Valley, is a low cost location of convenience where firms can realize savings by locating routine productive functions. Alternatively, a more complicated phenomenon may be at work. The industry relies on a highly educated workforce and supportive business culture. This has promoted interactions between large and small firms as well as the development of specialized knowledge and distinct local product specialization.

It is widely acknowledged that today's fast growing high tech industries don't fit the traditional mold described in industrial location theory. Unlike traditional mainstays of Portland's economy such as forestry, fishing, and farming, high tech firms are seen as "footloose"—capable of being located anywhere.

This conventional view of high tech firms views them as part of a Silicon Buffalo Herd, roaming the landscape of the West in pursuit of abundant water and greener grass. The decisive locational factor for these firms is often thought to be costs. Since making silicon chips uses relatively few raw materials other than water and electricity, it is assumed that the firms prefer to locate where water is abundant and electricity is cheap.

This picture of high tech economics rests on the notion that high tech firms are engaged in routine mass production. One simply buys computer chip producing machines, plugs them in, and starts producing chips. The machines are located wherever it is cheapest to operate them. In this view, Portland's principal advantages for high tech firms, particularly chip producers, are thought to be its relatively low cost electricity and abundant supplies of water. The region also has traditionally had a good supply of well-educated workers, and a nice quality of life. Until the early 1990s, housing prices were considered cheap relative to other high technology centers, and the state offered substantial tax incentives for large capital investments.

The "things look cheaper here" theory of Portland's high tech growth also fits with the absence of the one factor held to be decisive in the creation of a true high technology center—world-class higher education. The creation myths of the nation's two leading high technology complexes—Silicon Valley and Boston—maintain that the critical ingredient in generating successful high tech firms was a world-class research university

like Stanford or MIT. While no one claims that local universities prompted creation of the Silicon Forest, the acknowledged absence of such an institution in the Portland area reinforces the picture that Oregon is primarily a convenient, inexpensive location for branch plant production facilities.

While there is superficial evidence supporting the Silicon Buffalo Herd theory, it fails to adequately explain the growth of high technology industry in Portland. First, the attractiveness of abundant water and low electricity costs is greatly exaggerated. Intel's employees and their families, for example, use more water in their homes than Intel itself uses producing chips. The manager of one major Portland area semiconductor factory reported that his plant used only slightly more water than if he were growing 400 acres of potatoes. The location of other large semiconductor manufacturing complexes in Texas, Arizona and New Mexico all suggests that neither abundant water nor cheap electricity is an overwhelming locational advantage.

Two other factors are also mentioned as important to high technology location: tax breaks and quality of life. Since 1993, Oregon has offered a strategic investment program, which provides a limited property tax exemption for investments in excess of $100 million. While significant, this tax break is worth much less than the outright 3 year property tax exemption available in all of the state's 30 plus enterprise zones; yet only one of the major new investments announced in the 1990s has located in an enterprise zone rather than use the SIP program. Similarly, while the region's quality of life is available in lower cost, small urban areas such as Eugene, Salem, and Bend, most of the high tech development has been in Washington County, the heart of the most expensive region in the state.

The Silicon Forest is an alternative metaphor to the Silicon Buffalo Herd for explaining the development of high technology in the Portland metropolitan area. Life in the forest, we have come to know, is a complex ecology, with interdependence among life forms. Forest ecology also considers the role of succession forests, where the presence of one type of tree and related plants create the conditions that allow another species to flourish, and ultimately dominate the landscape.

This ecological metaphor is a good fit with metro Portland's high technology cluster. The critical element in the Silicon Forest is the highly specialized, world-class knowledge found in its firms and in the minds of its workers. The interactions between these firms, the dense shared market for skills, and the opportunities for ready links to other buyers and sellers, creates niches in metro Portland that don't exist in other regions. The region's business culture and a variety of supporting institutions play a key role in stimulating the high tech sector, particularly in encouraging the formation of new firms. Finally, there are clear connections over time between various aspects of the regional economy.

Knowledge creation is the underlying DNA of the Silicon Forest. Firms and workers in metro Portland's high technology cluster create new ideas ranging from software code and marketing plans to better semiconductor designs and more efficient chip production

processes. The heart of most of the region's high tech firms is their "core competence" to continually create new and better ideas in their specialties.

Ample evidence exists of the importance of knowledge creation. First, specialization is indicative of knowledge creation. We know that metro Portland firms are highly specialized and are not a random cross section of computer, electronics and software firms. Local firms also spend a large and increasing amount on research and development (R&D). The National Science Foundation estimates that Oregon businesses spent more than $1.1 billion on R&D in 1997, an amount that had quadrupled in a decade. The American Electronics Association estimates that Oregon high tech firms alone spent nearly $2 billion on R&D in 1998.

Another indicator of knowledge creation is the rising rate of patenting in the region. Patents issued to firms in metro Portland more than doubled in the 1990s and grew twice as fast as in the rest of the nation. The region is a research center for Intel, which gets more patents for its Oregon research than from all of the company's other US operations combined.

The region's high technology firms, in particular semiconductors, are not simply performing routine mass production. Products less than two years old generate half of all the sales of Oregon high tech, underscoring the importance of innovation and continuous improvement. Semiconductor production in state of the art half-billion dollar wafer fabs is more complex alchemy than assembly line. Wafer fabrication combines more than 30 different physical, chemical and electrical processing steps. Success in production is driven by a seemingly paradoxical combination of rigid adherence to carefully prescribed procedures and continuous experimentation with slide variations in procedures to further increase yields. Profitability in wafer manufacturing hinges on the ability of firms and their workers to quickly and continuously improve their ability to produce chips, which in turn depends on their ability to learn.

The people who work for high tech firms are the critical ingredient in the knowledge creation process. While these workers are likely to be well-educated scientists and engineers, knowledge creation is more than simply a process of accumulating large numbers of well-educated people. Developing specific related experience, for these researchers, engineers, and technicians is critical.

Another indicator of the role of knowledge creation has been the dramatic change in Portland's labor force. While it has always ranked somewhat above the national average, educational attainment in metro Portland increased sharply in the 1990s. By 1998, an estimated 34 percent of the region's population had attained a four-year college degree or higher compared with a national average of about 25 percent. By one count, metro Portland ranked among the ten best-educated large metro areas in the US in 1998. While many forces have contributed to rising education levels, skills demanded by the growing high tech industry has been an important factor.

Portland's experience is a striking exception to the rule that centers of high tech knowledge must emerge from world-class research universities. Labeled as mediocre in the media, Portland's educational institutions are regarded by most local high tech executives as at best adequate. Portland's leading firms, first Tektronix and more recently Intel, have played many of the key roles attributed to universities in other regions. . These businesses have established a strong reputation for intellectual excellence, attracted talented people to the region, and financed substantial and ongoing research efforts. In fact, Tektronix's outgoing CEO complained that the company's culture more like that of a research university than a profit-driven high tech business. It is doubtful that the region would have a significant high tech cluster in their absence. Whether they will continue to play this role for the region into the indefinite future is at best uncertain.

Like the old growth forest, the Silicon Forest has strong interdependencies among species. The critical mass of high tech firms in the region creates a wide and deep labor market for a range of specialized skills. For key engineering and management workers, knowing that there are many opportunities in Portland beyond the firm that might initially hire them lowers the level of economic uncertainty attached to relocating to Portland from elsewhere.

The importance of these interdependencies goes beyond the labor market. The presence of a concentration of high tech firms creates an ample local market for suppliers of a variety of goods and services. Firms providing ceramics, chemicals, plastics, metal parts and finishing, gases, and a variety of professional services such as marketing, design, engineering, and testing all benefit from the concentration of local manufacturers. Metro Portland also has a significant concentration of sales, service and support operations for firms that provide equipment for semiconductor production and other electronic processes. In addition, high tech firms can judge from the successful operation of major firms--like Intel--that the region has all of the resources that they need to operate successfully as well. Because of the high cost associated with downtime in production, such major manufacturers insist that spare parts and round the clock support be easily available.

Just as in the natural environment, evolution is a central and powerful force in the Silicon Forest. A key facet of that development has been the success of new locally grown firms that capitalize on and extend the region's knowledge base. The region is continuously producing such firms, its new species, some of which survive while others perish. One measure of this volatility is the membership of the American Electronics Association's local chapter. Half the firms that were members in 1998 did not exist a decade earlier; of those firms who were members in 1988, half no longer existed a decade later.

Underlying the continued evolution of the Silicon Forest is a business environment that is particularly conducive to the formation of innovative new businesses. Both the region's institutions (trade associations, service providers and government) and the local business culture encourage and support entrepreneurial behavior. The presence of a small but

growing base of venture capitalists, attorneys, accountants, marketing and financial specialists provides the critical intellectual resources needed to start new high tech firms.

The local business culture, descended in part from Tektronix, puts a premium on innovativeness and engineering excellence. Local business people have a small, but influential, number of role models of local start-ups such as Sequent, Mentor Graphics, and In-Focus that have done well, even though not becoming the next Microsoft or Amazon. Further, many in the Silicon Forest have close personal and professional ties to Silicon Valley and draw on these in starting, financing, and operating their firms.

The formation of new firms and their rapid growth has been a major force in the regional economy. Roughly 60 percent of the jobs in fast growing, highly paid, traded sector firms in the Portland metropolitan area between 1992 and 1997 were in electronics and software. As elsewhere, people who had previously worked in existing firms in the industry cluster form nearly all of the new businesses in the region.

IV. Dynamics of Growth in the Silicon Forest

New high tech businesses don't just pop up anywhere in Oregon; they are a product of a very specific set of environmental conditions. Just as one finds chanterelle mushrooms in Oregon's Coast Range and not in the high desert, one finds new high tech firms only in those places where the environment is right.

Technology is one key to growth in this environment. While the typical image of a startup firm is centered on a new product idea, such firms often coalesce around a clear understanding of a problem rather than a solution. Understanding this potential market can be even more important than an intimate knowledge of the technology involved. For example, having a detailed understanding of a technical problem, like the growing complexity of circuit design and the difficulty of managing large groups of engineers, is often the basis of a startup such as Mentor Graphics, a pioneer in computer aided design software.

Startups need more than just a good idea with a potential market. They depend on a team of talented individuals. Most startups are founded by a group of people who have worked with one another at some point in their career. Consequently, contacts developed during previous employment play a critical role in staffing startup firms. The fact that workers in startups are drawn from people who know one another tends to narrow the scope of managerial and technological expertise of the company.

The availability of venture capital is a critical element in the startup of new high tech firms. This venture capital is seldom a passive investment. Besides cash, venture capitalists bring a wealth of contacts and experience to startup businesses. Venture capitalists usually work with the firms they finance to improve their odds of success, most importantly, helping to recruit key managers, forming strategic partnerships with customers and suppliers, and advising the firms on business strategy. Consequently, the major constraint on a venture capital firm's operations is often the limited time of the

firm's experienced managers. While on paper it may seem easy to invest in a distant firm, in practice most venture capitalists invest very close to home. As a result, venture capital investment is much more highly concentrated in a few locations than other forms of capital. For example, in the first half of 1999 60 percent of all venture capital investment was made in just five metro areas; with 40 percent of the national total made in the San Francisco Bay area alone.

A region's business culture also plays a critical role in shaping startups. In the go-go culture of Silicon Valley it seems that everyone is focused on startups, deal-making, initial public offerings, and finding "the next big thing". By all accounts, this attitude does not typify the culture of metro Portland. To many, especially in the venture capital community, Portland seems hamstrung by its laid back culture: entrepreneurs seem less willing to sacrifice everything to grow the next Microsoft, and the community places little value on being wealthy and creating wealth. As a result, Portland seems unlikely to challenge Silicon Valley as the nucleus of high tech entrepreneurialism. On the other hand, many of those in the region have personal and business ties to Silicon Valley, enabling them to tap into that wellspring of talent and financial capital to support future growth.

There is a strongly path-dependent quality to the region's entrepreneurialism. The founders of new firms are almost always former managers, engineers, and other employees from the region's existing high tech firms. They inherit from their previous experience key knowledge about technologies, business strategy and practices, and the culture of commerce. Also, the contacts they made in previous employment typically provide the short-list of candidates for new firm's first hires. Thus the networks of contacts among workers at the region's existing firms powerfully shape the environment for new startups. Consequently the technological and managerial habits, routines, and practices of current industry limit and direct the possibilities for successive generations of business. The result is that growth tends to be an evolutionary process, a fact that becomes still more obvious when we consider the history of the Silicon Forest.

V. History Matters: Evolution of the Silicon Forest

While today's technologies are far more complex and sophisticated, much of what happens in high tech today can trace its roots to developments that occurred decades ago. For example, the pivotal influence in the development of the Silicon Forest was the success of Tektronix. Founded in Portland in 1946, Tektronix quickly became the world's foremost supplier of oscilloscopes. It had a dominant market share for what at the time was a critical piece of technology for designing, manufacturing, and servicing, all manner of electronic devices, including computers. Tektronix was very profitable, and plowed much of its profit back into new product development and design, in the process attracting and retaining a cadre of talented engineers. Consequently by the 1960s Tektronix was Oregon's largest manufacturing firm, and by the 1970s employed as many as 20,000 workers.

Like the succession forest, the growth of Tektronix transformed the environment in a way that made it possible for other firms to locate here. The Tektronix Board of Directors encouraged Intel to look at expansion sites in Portland, ultimately leading Keith Thomson to buy land for Intel's first Oregon wafer fabrication plant in Aloha in 1974. This was followed in the 1980s by the arrival of a number of Japanese electronics firms, and there was a flourishing of local startup firms, many descended from Tektronix.

While Tektronix was unquestionably the progenitor of Portland area high technology, even it was not born into a barren landscape. The company drew several key engineers from the Forest Service Radio Laboratory in Portland, which in the 1940's built sophisticated portable radios for firefighters. The Forest Service Lab also brought to Portland Doug Strain who would go on to found Electro Scientific Industries. Also before Tektronix, other firms, including the Forest Service Lab's local manufacturing supplier Radio Specialties, and Iron Fireman, a builder of aerospace instruments for Boeing, had trained a local workforce in electronic assembling. There were also a number of small, specialized local suppliers, including transformer winders, silk screeners, and others ready to serve Tektronix as it grew.

The point of any history of the electronics industry, however, is not to isolate causes and award credit for the Silicon Forest to any firm, individual, or event, but to illustrate connections. Many of the region's technological specializations trace their beginnings to Tektronix. The region is today a major center for display technologies, including flat panels (Planar Systems), video projectors (In-Focus) and related technologies (Pixelworks, Clarity Visual Systems). The presence in Portland of all of these firms is indirectly connected to Tektronix decision to produce its own oscilloscope tubes in the 1950's and it subsequent development of computer graphic display terminals in the 1970s.

Metro Portland is also home to three large printer manufacturers: Tektronix, Hewlett Packard, and Epson. The Tektronix printer operation, recently sold to Xerox, was an offshoot of technology developed for recording instrument readings. Similarly, the region's strength in semiconductor manufacturing equipment and electronic design automation software are also related to the competence developed early on for complex semiconductor manufacturing.

Such evolutionary processes are apparent in the formation of related and supporting industries as well. The nature and the capabilities of the region's supplier firms, especially in the metals and plastics sectors, have been shaped by the demands of high technology customers. The critical mass of firms in the region and their specialized needs have spawned or reshaped a series of professional services firms in construction, law, accounting, finance, public relations, and industrial design. The local competencies embodied in these firms have in turn helped facilitate the growth of additional local high technology businesses.

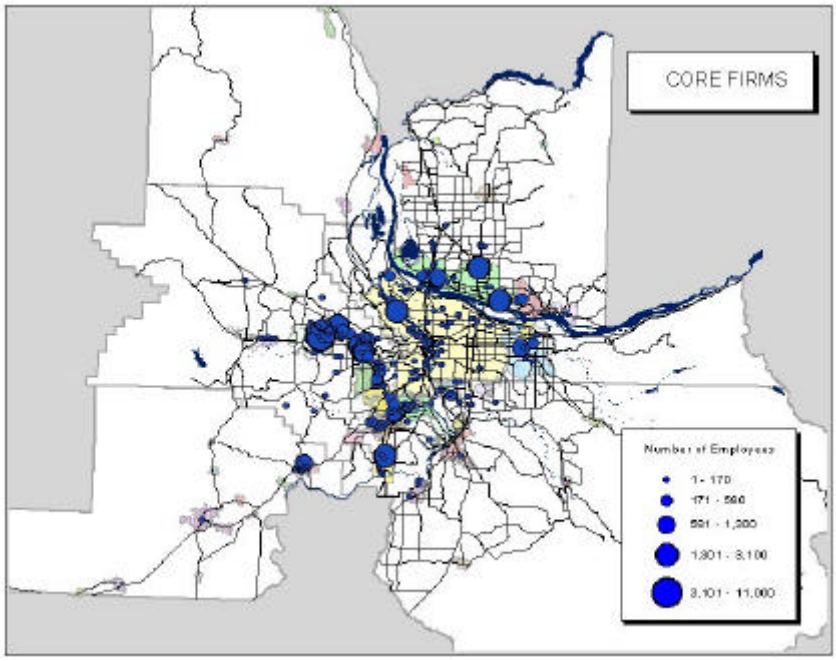
While perhaps clear in retrospect, there is nothing preordained or deterministic about the technological trajectories outlined above. As was the case in Portland's past, the region's

technological future is likely to develop as an extension and a refinement of the technologies and competencies of today following their own unpredictable path.

VI. The Geography of the Silicon Forest

Like the natural landscape, the landscape of the Silicon Forest has distinctive patterns and considerable variation from place to place. While some types of businesses (grocery stores, gas stations, coffee shops) are found spread evenly throughout the region, high tech firms are heavily concentrated in a few selected locations. The bulk of metropolitan Portland's high tech firms are concentrated in a Silicon Crescent from Hillsboro, following Highway 217 through Beaverton and Tigard and South along Interstate 5 to Wilsonville. There is a secondary concentration of firms in downtown Portland. A few relatively large firms are located well away from these concentrations—Wacker in Northwest Portland, Fujitsu and LSI in Gresham, and several firms in Clark County, Washington.

The Silicon Forest, 1999



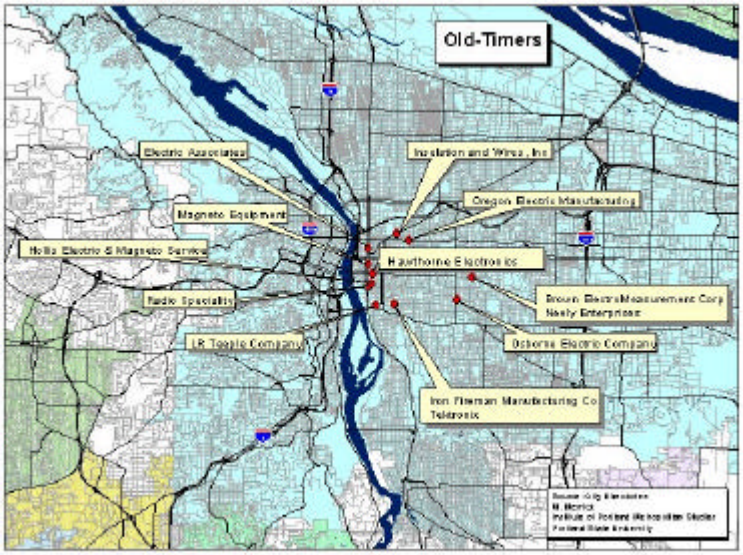
The strong clustering of firms in what we have called the Silicon Crescent described above points up the apparent advantages of locating near other similar firms. Most of the region's semiconductor makers, semiconductor manufacturing equipment producers, and electronic design automation firms, as well as their suppliers, wholesalers, and workers are all located within a short drive of one another in the region's west-side. The exceptions tend to be larger, vertically integrated producers, and multimedia and e-commerce software firms. While this proximity promotes collaboration, the biggest

reason for locating near other firms is probably the advantages it provides in tapping the industry's most important resource —skilled workers. Businesses located outside of the Silicon Crescent may find it harder to get to know and become known to workers already employed there. Like Silicon Valley, where workers can reputedly change jobs without changing carpools, the opportunity to tap into the labor pool is a powerful incentive to locate near other firms.

High tech firms are often called "footloose"—implying they can locate with equal ease in any location. The actual locational preferences of firms contradict that simple notion. Not only is high tech cluster activity specialized among metropolitan areas—a point we elaborate on in Section VII—but high technology firms tend to specialize within metropolitan areas as well.

The propensity to cluster has historical roots. In the 1940s, when the region's electronics industry was just beginning to grow, most firms were clustered in a small industrial neighborhood in Southeast Portland, in what might have been termed the vacuum tube forest. Led by Tektronix, the high tech industry expanded in Washington County in the 1950s, and has continued to do so ever since.

The Vacuum Tube Forest, Circa 1950



The location patterns of high technology businesses do not exhibit the randomness one would expect from a supposedly footloose industry. While the presence of natural resources or transportation facilities does not constrain their location in the same fashion as more traditional industries there is still a powerful logic to location patterns among high technology firms. In addition to proximity to one another, and to specialized suppliers, the most critical factor in their location decisions may be convenient access to the region's pool of talented workers.

VII. Comparing Portland to Other Metropolitan High Tech Centers

We can gain added perspective on the scale and character of metropolitan Portland's high technology industry cluster by comparing it to similar metropolitan areas around the nation. Examining not just employment data, but also characteristics of leading firms, the kinds of innovation present, and the historical roots of their development, A comparative analysis of thirteen metro areas—including Austin, Boston, San Jose, Phoenix and Denver— shows that metropolitan specialization is a key attribute of high technology industries. While many of the processes driving high tech growth are similar across all regions, each region has its own particular strengths, evolutionary path, and technological trajectory.

High technology specializations vary dramatically from place to place. Different regional clusters specialize in certain technologies and have major concentrations of firms and employment in relatively few industries. A few places, like Silicon Valley, excel in many areas. However, most metro areas, even those labeled high tech centers, usually concentrate in just a few products or technologies. This means that a region that is strong in one area, such as medical devices, does not necessarily have an edge in another area, like telecommunications, semiconductors, or software.

Typical Product Specializations for Selected Metropolitan Areas

Region	Product Specializations
Boston, MA	Computers, Medical Devices, Software
Atlanta, GA	Telecommunications, Databases
Phoenix-Mesa, AZ	Semiconductors
Minneapolis-St. Paul, MN-WI	Computers, Peripherals, Medical Devices
San Diego, CA	Communications Equipment, Biotechnology
Seattle-Bellevue-Everett, WA	Software, Biotechnology, Aerospace
Denver, CO	Telecommunications Equipment & Software, Data Storage
Portland-Vancouver, OR-WA	Semiconductors, Display Technology, SME/EDA, Wafers
San Jose, CA	Semiconductors, Computers, Software, Communication Equipment, SME/EDA, Data Storage
Sacramento, CA	Computers, Semiconductors
Salt Lake City-Ogden, UT	Software, Medical Devices
Austin-San Marcos, TX	Semiconductors, Computers, SME
Raleigh-Durham-Chapel Hill, NC	Pharmaceuticals, Computers, Databases

Note: SME – Semiconductor Manufacturing Equipment; EDA – Electronic Design Automation software.

Knowledge differs from place to place. Specializations apparent in employment data are mirrored in patterns of knowledge creation, as evidenced by patent data. Similarly, venture capital investment patterns follow the same specializations. Inventors and investors in any given area are likely to focus their efforts in areas closely related to current economic strengths of the region.

As a result, history matters in shaping regional economies. Industrial and knowledge specializations tend to persist over time. While some areas acquire or grow new technological specializations, such as Austin in semiconductors, other places demonstrate a remarkable continuity in specific technological prowess over many generations of firms

and technologies. Examples of this phenomenon include Minneapolis' role in medical devices, and computer storage and telecommunications in the Denver/Boulder region.

Such historical lock-in can be good or bad. While technological specializations can produce powerful forces for growth in expanding industries they can easily produce stagnation or decline when an industry or technology is displaced. In some cases, technological specializations can undermine economic growth. Both Minneapolis and Boston, which were major centers for computer design and production in the era of mainframes and minicomputers suffered serious downturns when markets for these products were overwhelmed by the PC revolution.

High tech growth appears to be an ongoing, evolutionary process. While areas do specialize, they tend not to remain constant over time. As industries and technologies change, the mix of firms and knowledge present in specific metropolitan areas evolves. In practice, development processes appear to be cumulative and path dependent: a region's opportunities for development today are determined, in part, by the kinds of development that have occurred in the past. In retrospect, the importance of pivotal events—like the initial commercialization of key research breakthroughs, the acquisition of substantial and sustained government research and procurement spending, and some industrial relocation decisions—is clear.

High technology is neither a monolithic industry grouping nor a fungible set of products, production methods, or technologies. Almost by definition, high technology goods are highly differentiated. Neither end products, production processes, nor much detailed technical knowledge is completely interchangeable among firms. Thus, common statistical analyses grouping inherently disparate firms such as medical devices, semiconductors, telecommunications, and software into a single category of "high technology" miss an essential aspect of high technology. Attempting to explain industry behavior as if firms were homogenous units driven by a common set of factors is likely to be substantially misleading and incomplete.

One area stands out: Silicon Valley plays a special leadership role in high technology. The San Jose metropolitan area distinguishes itself from other high tech centers based on the scale, breadth, and leadership qualities it possesses. It has more high tech employees than any of the other regions's studied, a broader array of production and technological competencies, and a larger volume of patents than any other region. Alone it accounts for nearly 40 percent of the nation's reported venture capital investment. The largest Silicon Valley firms are all locally headquartered, and account for more headquarters locations of high tech enterprises in other metro areas than all of the other regions reviewed in this study.

This comparison of high technology industries in a number of metropolitan areas shows that while there may be broad similarities in the nature of high tech activities, the forces that shape growth are peculiar to individual metropolitan areas. Each region has its own history, technological specializations, and patterns of growth at different times.

VIII. How Does Portland Fit the Model For Industry Clusters?

Scholars have sought to describe dynamics of industrial clustering and categorize industry agglomerations. Alfred Marshall described some of the most important ingredients of industry clusters more than a century ago. His work has been rediscovered and gained new popularity, based on case studies of Italian industrial districts and other agglomerations. Geographers, like Ann Markusen, have worked to create a system for classifying and differentiating various kinds of industrial districts. Business strategist Michael Porter emphasized the importance of local rivalries, customer and supplier bases, and input availability to the development and competitiveness of industry clusters. Finally, Annalee Saxenian's comparative study of two prominent high technology clusters—Silicon Valley and Boston's Route 128, emphasized the importance of the local business culture in shaping the development and success of industry clusters. How well do each of these theories fit Portland's high technology cluster?

Alfred Marshall outlined three forces promoting the development of industry agglomerations: labor market pooling (the advantages to firms and workers specializing in a particular craft or industry that accrue from being close proximity to one another), specialized suppliers (the fact that larger concentrations of a particular industry will support finer specialization by local supplier firms) and knowledge spillovers (ideas and best practices circulate easily and quickly in a particular locality, making firms located their more innovative and productive) (Marshall, 1920).

This study's analysis of Portland's high technology cluster provides evidence of all of Marshall's factors. Firms frequently cited the availability of labor, both in the form of existing labor force and the relative ease of recruiting new workers from elsewhere, as key advantages to the metropolitan area. The metro region also exhibits a significant concentration of specialized supplier firms. Finally, there appear to be some significant knowledge spillovers, particularly in the formation of new firms, which embody and rearrange the region's knowledge specializations to establish new firms.

Ann Markusen suggests that industry agglomerations can be classified into four broad categories:

- Marshallian industrial districts, characterized by, among other things, small locally owned firms, low scale economies, substantial intra-district trade, low degrees of linkages to external firms and workers committed to the district rather than to individual firms.
- Hub-and-Spoke districts, a region dominated by one or a very few large, vertically integrated producers, with large-scale economies, intra-district trade between large firms and suppliers, and substantial non-local connections to suppliers and markets.
- Satellite industrial platforms, dominated by large, externally-owned and –headquartered firms, minimal intra-district trade, absence of long term commitments to local suppliers, high degree of interactions with external firms, particularly corporate parents in other locations.

- State-anchored industrial districts that are an outgrowth of a major public sector institution such as military bases or state capitals (Markusen, 1996).

Portland's high tech sector might best be described as an admixture of all of the first three types of industrial agglomeration. In its early days, when a majority of the region's employment was in a single firm—Tektronix—the region could be fairly characterized as a hub-and-spoke district. The location of a number of large outside investments by US and Japanese firms in the 1970s and 1980s, were at least initially consistent with the view that the region was becoming more of a satellite platform district. Indeed, many of the firms in the region today are externally owned. Nonetheless, the growth of many new start-up and spin-off firms, particularly in display technology, semiconductor manufacturing equipment and software, and the expanding research and development functions of many outside headquartered firms mean that substantial portions of the region resemble the Marshallian industrial districts. Geographically, the firms in the heart of the Silicon Crescent on the region's west side exhibit many of the characteristics of this kind of industrial district, inter-firm mobility among workers, entrepreneurship and so on. Many firms that could be characterized as export platform businesses are located more peripherally.

Michael Porter's diamond of competitive advantage emphasizes the critical importance of localized rivalry, inputs, suppliers and customers (Porter, 1990). Except for the availability of their principal input, skilled labor, most firms interviewed for this project did not put a strong emphasis on the proximity of these factors. Most major competitors, equipment vendors, and customers are located outside the region. Firms underscored the importance of being well connected with world-class customers and suppliers regardless of their location, be it California, Texas, Japan or Taiwan. While some local suppliers of wafers and equipment cited the availability of major customers, such as Intel, as a modest competitive advantage, the larger manufacturers tended to view the proximity of a supplier base as a convenience rather than a source of advantage. Producers in the region also tend to have important non-local contacts, especially to customers in Asia and Europe, and to competitors and equipment vendors in Silicon Valley.

AnnaLee Saxenian's comparative study of Boston's Route 128 and the Silicon Valley argued that differences in the business culture of the two regions played a decisive role in their development (Saxenian, 1994). In her view, the open, collaborative, risk-taking culture of Silicon Valley enabled it to be quicker to respond to technological and market opportunities than the more internally focused, hierarchical structures of Boston firms. Interviews confirm that Portland's business culture much more closely resembles the open and innovative model of Silicon Valley. Early firms in the region consciously modeled themselves after Silicon Valley stalwarts like HP, but Portland's smaller size and laid back lifestyle have resulted in a lower level entrepreneurship.

While none of these models precisely fits the high technology cluster in the Portland metropolitan area, each of them provides some perspective on how the region has developed, and why it is structured as it is today. It is particularly important to recognize the dynamic quality of the region's high technology industry: the structure and

characteristics of high technology in metro Portland have changed dramatically in the past two decades. In retrospect, there is a clearly evolutionary quality to the region's development path. The success of Tektronix triggered the assemblage of a critical mass of skilled workers and infused the region with its own business culture, akin to Silicon Valley, but less intense. The region's pool of skilled labor provided a base for outside firms to establish export platform-type operations. Over time some of these operations, most critically Intel, shifted higher order research and development functions to the region. The combination of talented people, the downsizing of Tektronix, and the region's technological specializations, leavened by a few entrepreneurs and some venture capital led to a flourishing of indigenous startups, particularly in the 1980s, and again in the past few years. Another wave of outside investment, particularly in semiconductor production, solidified the region's status as a major high technology center.

Conclusions

The growth of the Silicon Forest has been the major factor propelling the Portland metropolitan economy during the 1990s. Simple explanations—like the cost-minimizing Silicon Buffalo herd metaphor—have a grain of truth, but don't capture the depth and breadth of what's driving high technology.

At its root, growth is being driven by a critical mass of high tech firms and workers who are creating very specialized new knowledge. Talented, imaginative people with a detailed understanding of the problems and opportunities of particular technologies are central to knowledge creation. This process is fueled by the competencies of the existing industrial base, business strategies of current firms, and the entrepreneurial efforts of those who start new firms. It also requires a business culture that stimulates risk-taking, as well as a critical mass of venture capitalists, lawyers, accountants and others who can assist in starting new businesses.

At its core, new knowledge creation is about being different, imaginative and better rather than being cheaper. Tax breaks and low costs for some inputs may accelerate the process of growth, but they are not the necessary preconditions for starting it. As Stanford economist Paul Romer has said:

> As the world becomes more and more closely integrated, the feature that will increasingly differentiate one geographic area (city or country) from another will be the quality of public institutions. The most successful areas will be the ones with the most competent and effective mechanisms for supporting collective interests, especially in the production of new ideas.(Romer, 1992)

One of the new ideas that we should take to heart is the presence of not just the physical landscape, but also the knowledge landscape around us. The rich variation in knowledge from place to place will shape our economic future every bit as much as the variations rainfall, climate and soils shaped our economic past.

References

Markusen, A. (1996). Sticky places in slippery space: a typology of industrial districts. Economic Geography, 72(3), 293-314.

Marshall, A. (1920). Principles of Economics. London: Macmillan.

Porter, M. E. (1990). The Competitive Advantage of Nations. New York: Free Press.

Romer, P. M. (1992). Two strategies for economic development: using ideas and producing ideas. Proceedings of the World Bank Annual Conference on Development Economics, 63.

Saxenian, A. (1994). Regional Advantage: Culture and Competition in Silicon Valley and Route 128. Cambridge: Harvard University Press.

Regional Connections
High Technology Cluster Study

The Regional Connections project has undertaken an analysis of the Portland Metropolitan Area's high technology industry. The project's findings are detailed in five working papers.

WP1: Overview of the Silicon Forest
The Silicon Forest, the metropolitan cluster of computer, electronics, instruments and software firms in the Portland area consists of more than 2,000 businesses employing more than 70,000 people and paying average wages in excess of $50,000 annually. The Silicon Forest account for more than 10% of semiconductor production in the US and more than a third of additions to semiconductor production capacity during the mid 90s. As a result this cluster is growing nearly three times as fast as these industries nationally, and exports over $3 billion from the Portland area. In addition, Silicon Forest firms create demand for a wide range of supporting industries in metals, plastics, staffing services, legal, engineering and professional fields, and highly specialized construction and finance. The Silicon Forest is a critical factor in the region's economic well-being.

WP2: Portland's Knowledge Based Economy
The driving force in Portland's high technology industry expansion is the emergence of the region as a key center for knowledge creation in form of enhanced production processes and new products. Various indicators underscore the region's progress in knowledge creation. Patenting activity is growing more rapidly in the metro area than in the nation, spurred largely by the growth of high technology, which accounts for the bulk of the region's patent activity. Intel is the region's largest patentee, and Oregon-based researchers account for a majority of Intel's US patents. Knowledge-workers abound: one-third of adults now have a four year degree or higher level of education, placing metro Portland among the ten best educated larger metropolitan areas. Unlike other high tech centers, Portland's strengths in high tech knowledge creation and strong educational attainment seem to have been achieved without the presence of a perceived world-class research university. The growth of the high tech industry itself, particularly large firms such as Tektronix and Intel, have played a crucial role in stimulating the development of the region's knowledge base. The Silicon Forest is not simply a manufacturing platform for ideas generated elsewhere; it is an important center of research, development and innovation in its own right, and this process is driving the region's growth.

WP3: Spin-offs, Startups and Fast Growth Firms in the Portland Regional Economy
The Silicon Forest renews itself and grows through the ongoing process of creating new businesses. The process of creating startup and spin-offs businesses builds on the knowledge base of the region's experienced workers and their personal and professional networks. Venture capitalists and a range of other professionals—attorneys, accountants, and real estate operators—provide cash and services to help new companies start and grow. This growth process is highly localized and path-dependent. New firms typically borrow and build on the technological strengths and managerial practices present in the

local industrial base. Fast growing high tech businesses play a decisive role in driving the region's economic growth. Between 1992 and 1997, more than sixty percent of the jobs created in the Metro Portland's high wage, fast growth businesses were in electronics and software. Most of the largest fast-growing technology businesses are descendants or close relatives of some of the region's largest high tech firms.

WP4: Comparison of High Tech Centers

A number of mid-sized metropolitan areas throughout the United States have frequently been identified as current or emerging centers for high technology business. This paper uses both aggregate and firm level data to analyze the economic growth, knowledge base and employment structure of the high technology industry in 13 metropolitan areas. There are significant variations in industrial composition, firm structure, technological specializations, and venture capital investment from region to region. While the term "high technology" is broadly used to describe the economies of these metropolitan areas, this analysis shows that each area tends to have its own areas of distinctive specialization. Specialization and differentiation are inherent qualities of high technology. There appear to be durable and persistent tendencies for metropolitan high tech development that are unique to each region.

WP5: Geography of the Silicon Forest (forthcoming)

Portland's high technology businesses are tightly clustered in a few specific locations in the metropolitan area. The bulk of the region's electronics firms and employees are located in a Silicon Crescent that stretches from the Hillsboro Airport to Wilsonville, following Highway 26, Highway 217, and Interstate 5. Several of the region's larger high tech firms, including several foreign-owned firms, silicon wafer producers, and large-scale fabs, are located outside the silicon crescent. Smaller, start-up, and locally headquartered firms are more likely to be located in the crescent. Multi-media software firms are located disproportionately in the central city. The region's high tech cluster has shifted since the cluster began; in the 1940s, the region's electronics firms were tightly clustered in Southeast Portland between Hawthorne Street and Powell Boulevard. The industry suburbanized in the 1950s, 60s and 70s.

Regional Connections is an ongoing effort to analyze and explain the structure and performance of the Portland Metropolitan Economy, sponsored by Portland State University's Institute for Metropolitan Studies. Funding for this project has been provided in part by lottery funds from the Regional Strategies program for Multnomah and Washington Counties, administered by the Portland Development Commission and the Oregon Economic and Community Development Department, and from the American Electronics Association and Portland State University.

Regional Connections work products include a technical report - "Progress of a Region: The Metropolitan Portland Economy in the 1990s"- briefings on the regional economy and a series of working papers summarizing the project's studies of the region's industry clusters, including high technology, metals, creative services and nursery products. For more information about Regional Connections, contact Ethan Seltzer at 503-725-5170 or visit our website at www.upa.pdx.edu/ims/regcon/regecon.html.