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FEATURE

What is the Role of Universities in High-tech Economic Development? The Case of Portland, Oregon, and Washington, DC

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ABSTRACT This paper focuses on two regions in the United States that have emerged as high-technology regions in the absence of major research universities. The case of Portland's Silicon Forest is compared to Washington, DC. In both regions, high-technology economies grew because of industrial restructuring processes. The paper argues that in both regions other actors—such as firms and government laboratories—spurred the development of knowledge-based economies and catalysed the engagement of higher education institutions in economic development. The paper confirms and advances the triple helix model of university–government–industry relationships and posits that future studies have to examine degrees of university-region engagement.

Introduction

The role of the university in economic development has been prominently discussed in the literature on high-technology regions. The most well-known case is Stanford University's involvement in the growth of Silicon Valley in California. Similarly, the case of Boston and the influence the Massachusetts Institute of Technology exerted on the growth of the high-technology industry along Route 128 has also been extensively discussed (Saxenian, 1985; Leslie, 1993, 1994). However, if we look beyond these

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two cases, we find that the literature provides many more multi-faceted answers to the question about the role of universities on urban and regional high-technology economic development. For example, studies of regions other than Silicon Valley and Boston's Route 128 highlight that the presence of a university is not a guarantee for developing a vibrant high-technology economy. In addition, a different set of studies of regions with vibrant high-technology economies and a notable absence of university engagement raise important questions about the role of the university in economic development.

This paper focuses on two high-tech region in the United States that have emerged without engagement of a major research university. In particular, I will discuss the case of Portland, Oregon, where over the last decades an industry has evolved that is heavily focused on high-technology manufacturing and where there is no significant research university present. The other region is Washington, DC. Here, a sizeable information technology service industry evolved without significant help from existing higher education institutions.

The paper hypothesises that in both cases other actors—notably firms and government agencies—have played important roles in the creation of a knowledge-based economy. Moreover, in these regions, firms and government agencies responded to broader socio-economic changes that began to take hold in the 1970s by changing their vertically integrated organisational structure to decentralised industry clusters. This process allowed these regions to emerge as high-technology industrial districts without major involvement or the presence of world-class research universities. I further argue that existing higher education institutions are reacting to these economic changes by becoming more responsive and interactive with the regional economy. The decentralisation processes and the creation of a networked economy by small and medium-sized firms provided higher education institutions with a 'new client base' (OECD, 1999, p. 21). The case studies serve to illustrate and test theories about the emergence of regional innovation systems and university-region engagement. In particular, I will show how the evolution of a regional high-technology industry catalysed new cooperative arrangements between firms, higher education institutions, and local and state government.

Literature Review

The role of the university in economic development and the emergence of high-technology regions have to be evaluated within the broader context of socio-economic changes. In particular, prominent high-technology regions such as Silicon Valley evolved because of substantial economic changes that started in the 1970s when many firms began to change their strategies to respond to increased international competition. Corporations that once were vertically integrated and characterised by Fordist organisation principles, such as the separation of corporate functions, mass production techniques, in-house corporate R&D laboratories, began to adopt more flexible structures to become more responsive to changing markets (Piore & Sabel, 1984). As a result, regionalised networks of small and medium-sized firms emerged and began to function as suppliers, thereby substituting internal production capabilities (Hirst & Zeitlin, 1991). The outcome of these macro-economic changes is the creation of regional innovation systems that 'consist of firms, large and small, comprising an industry sector in which network relationships exist or can be commercially envisaged, research and higher education institutes, private R&D laboratories, technology transfer agencies, chambers of commerce, business associations, vocational training organisations, relevant government agencies and appropriate government departments' (Braczyk *et al.*, 1998, p. 10).

Regional innovation systems—also referred to as industry clusters (Porter, 2000), industrial districts (Piore & Sabel, 1984), or learning regions (Lundvall & Johnson, 1994)—are governed by associative collaboration and cooperation that is built on mutual trust resulting from repeated interactions between actors such as firms, university laboratories, and government agencies (Harrison, 1992). The benefit of such interactions is the ability to rapidly adopt knowledge and share information, an important attribute for high-technology firms. These trends spurred the development of high-tech regions such as Silicon Valley, Boston's Route 128, or North Carolina's Research Triangle (Luger & Goldstein, 1990; Saxenian, 1994).

As the economy changed and regional innovation systems emerged, the relationship between higher education institutions, firms, and government agencies transformed. Universities have become important components of a regional economy. This contrasts with the early post-war era when universities represented traditional 'ivory towers' with few—often only at arm's-length—connections to their immediate regional environment (Etzkowitz & Leydesdorff, 2001a). Responsible for increased university-region engagement is also the decline in federal and state financial support for universities, which now have to seek alternative funding sources. In addition, the rise of regional innovation systems has offered universities a much broader and regionalised base of partners to work with. Conversely, firms have taken on some of the roles universities used to provide: Etzkowitz observes that 'companies raise training programs to higher technical and intellectual levels (e.g. "Motorola University") and sponsor scientific conferences' (Etzkowitz & Leydesdorff, 2001b, p. 142). These developments stand in contrast with the Fordist period before 1970s when vertically integrated firms did not interact with other regional actors to the extent they do now in regionalised post-Fordist networks. In addition, state and local governments have become more interested in creating knowledge-based economies. Through their policies and programs, they proactively support the co-evolution of industry and universities.

Etzkowitz & Leydesdorff (1995) capture the intertwined nature of university, industry and public policy in their concept of the 'triple helix of university-industry-government relations.' They argue that the relationship between universities, industry, and government is becoming increasingly intertwined through a spiral of connections in which each actor transforms itself, is influenced by the others through trilateral relationships, and exerts a recursive effect upon the regional environment. Gulbrandsen (2001) presents the cases of Cambridge (UK) and Grenoble (France) where regional cooperation between universities, local government, and industry has formed a regional triple helix that was beneficial for economic development. He cautions, however, that to be successful with entrepreneurial university initiatives, a region needs to develop a supportive environment. Several other scholars noted that a so-called 'innovation milieu' needs to be in place to absorb spillover effects resulting from industry-university relationships (Crevoisier & Maillat, 1991; Feldman & Desrochers, 2003).

The vantage point for examining the triple helix of university–industry–government relationships has primarily been the university and its response to regional economic development opportunities (OECD, 1999). Many studies have focused on the entrepreneurial role of universities as 'regional innovation organisers' (Etzkowitz, 2001, p. 147). Universities are playing a greater role in meeting regional labour market needs, they orient their research activities towards local industries by creating dedicated research centres and mechanisms to transfer technology and knowledge, and they have become much more proactive in community service and outreach (OECD, 1999). Together, these trends point towards pro-active engagement by universities with regional needs. There are, however, differences in the degrees or 'tiers' of engagement of universities in their regional economies (Boucher *et al.*, 2003).

These differences are evident when we examine the literature on the role of higher education institutions in the creation and evolution of high-technology regions. There are three sets of studies about university engagement in high-technology development. The first set provides evidence for the importance of research universities in the evolution of high-technology regions. The most prominent examples include Silicon Valley and Boston's Route 128 (Saxenian, 1985, 1994). Other studies focused on the influence of universities on high-technology development in regions such as Austin (Smilor *et al.*, 1989), North Carolina's Research Triangle Park (Luger & Goldstein, 1990), and San Diego (Walcott, 2002; Walshok *et al.*, 2002). The lessons from these studies are threefold: higher education institutions such as Stanford University or MIT were able to provide regions with the skilled labour pool, with the creation of knowledge, and with entrepreneurs who start businesses.

The second set of studies, however, provides a contradictory view of high-technology economic development. There are numerous examinations of regions in which higher education institutions have not influenced regional economic growth. In some of these cases policymakers have tried to replicate the 'Silicon Valley model'. Examples include the study of John Hopkins University's influence on Baltimore's economy (Feldman, 1994), Cleveland's attempt at leveraging R&D laboratories for economic development (Fogarty & Sinha, 1999), and the efforts of Stanford's Frederick Terman in selling the 'Silicon Valley model' to regions or countries as diverse as New Jersey and South Korea (Leslie & Kargon, 1996). In all three regions one essential component was missing: Each region was lacking a supportive regional innovation milieu (Crevoisier & Maillat, 1991; Castells & Hall, 1994) that could have provided the basis for the spillover effects from the existing higher education institutions.

The third set represents cases that are the most relevant for this paper. These studies examined regions that were able to grow high-technology industries without the involvement or the presence of major research universities. In the case of Seattle for example, the University of Washington did not influence the evolution of the aerospace and the software industry (Gray *et al*., 1996, 1999). Another example is Colorado Springs, where primarily military facilities played the role of anchor tenants for a budding high-technology economy (Markusen *et al*., 1991). These studies point to the fact that existing firms or other types of institutions can function as 'anchor tenants' (Feldman, 2003). In some cases, researchers have highlighted that the universities in these region's 'responded' to high-technology growth by expanding and redirecting their science and technology education and research programs (Markusen *et al*., 1991). This third explanation notes that firms or other industry actors can spark the triple helix of university–industry–government relationships.

Taken together these studies provide an interesting mix of evidence about the role of the university in the creation of high-technology regions. The literature seems to confirm that the presence of a university is neither a sufficient nor a necessary precondition for creating high-technology economies. In some cases, university engagement has been more proactive (Silicon Valley, Boston) and in other cases, it has been reactive (Colorado Springs). All cases illustrate university–region engagement in high-technology with varying success. Success in the absence of a major research university seems to depend on two conditions: first, there needs to be an 'anchor tenant' or some kind of institution that provides impetus for regional high-technology growth. Second, the mere presence of such an anchor tenant is not enough. In addition, the region has to develop an environment in which high-technology labor, knowledge, and entrepreneurial activity can thrive and create positive economic development impacts. Furthermore, we need to develop a better understanding of the different degrees or, as Boucher *et al*. (2003) calls it, 'tiers of engagements' that universities may develop in high-technology regions.

Research Questions and Methodology

To answer the question of how high-technology regions evolve in the absence of a university and what the role of higher education institutions is in these regions, one has to think about the role of the university in the development of high-technology industries in general. In their discussion of 'technopoles,' Castells & Hall (1994, p. 230) note that 'universities in fact may play three different roles in the development of a technopole'. The first role is to generate new knowledge through research. The second function performed by universities is the training of a high-technology labour force. Third, universities function as incubators and help with the creation of entrepreneurial ventures. To examine regions that lack a university or whose high-technology economic development has not been influenced by universities, one needs to analyse these regions from the perspective of these three functions.

For this research the following questions are posed. In what ways have Portland and Washington, DC developed a high-technology labour pool, knowledge, and entrepreneurship? What regional economic actors have functioned as 'surrogate universities' in these two cases? How do the two regions compare to other high-technology regions, in particular to regions where university involvement has been prominent? What is the degree of engagement of the existing universities in these regions? Do the two cases confirm or even advance the theory of the triple helix of university–industry–relationships?

I will use theories of the emergence of post-Fordist high-technology regions and concepts developed to explain the relationships between university, industry, and government. In particular, I utilise the triple helix model of the university–industry–government perspective. However, in the case of Washington, DC and Portland, the analysis will start with an examination of industry evolution and will then focus on the responses by higher education institutions. In doing so, I am adopting an evolutionary perspective through which I hope to be able to add meaning to how industry influences university–region engagement.

To answer these questions, I use a case study methodology. In particular, I conducted an extensive empirical study of the evolution of Portland's Silicon Forest (Mayer, 2003). From 2001 to 2002, I completed more than 30 key informant interviews. In addition, I carried out a genealogy survey of high-technology firms to assess the role of two major high-tech firms as incubators for new start-up companies. Additional data about industry employment, venture capital, patent registrations, and corporate histories were collected to illustrate developments in knowledge creation and employment growth.

The Washington, DC case study serves as a comparative case to the Portland examination. Thus, I will be able to go beyond a single case study and assess the applicability of the triple helix model in which actors other than universities take a lead in creating a high-technology region. For Washington, DC, I utilised a meta-analysis of existing case studies to illustrate broader applicability of the triple helix model. In addition, I have conducted extensive analyses about the influence of federal contracting on the Washington, DC regional economy. Qualitative data were collected through a series of focus groups on emerging technologies in 2004 (Mayer, 2005a; Mayer *et al.*, 2005).

A Comparison of Portland and Washington, DC

Washington, DC and Portland, Oregon, represent two regions that generally have ranked behind traditional leaders such as Silicon Valley or Boston. However, their high-technology economies gained recognition in a variety of studies and reports. The Progressive Policy Institute (2001) ranked Washington, DC sixth and Portland 15th. In a Milken Institute study (DeVol, 1999), Washington, DC also ranked sixth while Portland's rank was 26. While rankings like these are problematic for determining a region's high-technology economy (Chapple *et al*., 2004; Cortright & Mayer, 2004), they can give us a general idea about a region's 'high techness'. If we compare Washington, DC and Portland along the three dimensions of labour, knowledge creation, and entrepreneurship, we can gain a more detailed picture of the two regions (see Table 1).

While data on patent registrations, venture capital, and publicly traded companies are far from being accurate measures of innovation and entrepreneurship, they provide us with a comparative perspective of the two regions in relation to other US high-tech areas regarding their economic development capacities.[1] Patent data, for example, do not reveal inventions that are not registered as patents, such as software, and leave out a large share of high-technology products and processes (Archibugi & Pianta, 1996). However, patent data can highlight the level of innovation activity registered with the US Patent and Trademark office. Similarly, venture capital data reveal funding available to only a small fraction of start-up firms—primarily those with great expectations for returns on investments—and do not capture the full range of entrepreneurship. However, the data can illustrate the degree to which high-growth entrepreneurial ventures receive funding in a region.

While Washington, DC boasts a bigger high-technology labour market, the region is not as innovative as Portland, as evidenced by the average growth rate of patents and the higher number of patents per 100,000 populations. Both Portland and Washington, DC share similar ranks for measures of entrepreneurship. Compared with other high-technology regions in the United States, Portland and Washington, DC are generally less entrepreneurial.

In contrast to Portland, Washington, DC has had a higher influx of venture capital. On average, between 1995 and 2003, Portland has seen $229 million invested in venture capital. Washington, DC, in contrast, has

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[1] Data of high-technology employment is limited to the years 1997 to 2000 because of changes in the industrial classification system and the associated difficulty in comparing longitudinal data. In 1997, the United States adopted the new industrial classification system called North American Industry Classification System (NAICS), which replaced the Standard Industrial Classification (SIC). The high-technology industry is defined as SIC 357: Office and Computing Machines, SIC 36: Electric and Electronic Equipment, SIC 38: Instruments and Related Products, and SIC 737: Computer and Data Processing Services. This definition follows the definition used by the Oregon Employment Department as well as Cortright & Mayer (2001).

Table 1. Comparison of Portland and Washington, DC MSA to other high tech regions

	Labour			Knowledge Creation			Entrepreneurship	
	Total high-technology employment	Average growth rate	Location quotient	Total number of patents	Average growth rate patents	Patents per 100,000 population	New publicly traded companies rank	Venture capital rank
	2000	1997–2000	2000	1999	1990–1999	1999	2001	2001
Portland	64,891	4.2%	1.74	930	8.8%	49	11	10
Washington	177,092	8.7%	3.32	2,030	5.4%	27	17	9
Silicon Valley	285,212	3.8%	7.32	5,664	14.8%	339	1	1
Boston	222,543	2.7%	1.85	3,806	6.2%	63	4	4
Austin	76,658	6.9%	2.96	1,571	14.9%	130	5	3
San Diego	67,866	5.4%	1.30	1,748	8.3%	63	7	7
Seattle	84,703	9.9%	1.59	1,296	8.2%	54	2	2

Source: Bureau of Economic Analysis, US Patent and Trademark Office, Progressive Policy Institute (Atkinson & Gottlieb, 2001)
Note: All data is for the metropolitan statistical area. Patent data at the metropolitan level is only available until 1999

had average investment of $1.6 billion during the same time period. Both regions experienced significant declines since 2000 when the booming Internet period ended.

Washington, DC and Portland also contrast regarding their high-technology industry specialisation. Washington, DC firms are predominantly found in information technology services, Internet services, telecommunications and biotechnology. In short, the DC region has a service-oriented high-technology economy. The Portland region is a manufacturing-oriented region and specialises in semiconductors, display technology, semiconductor manufacturing equipment, electronic design automation, and wafer production.

High-technology Economic Development in the Absence of a University

How have Washington, DC's and Portland's high-technology economies evolved in the absence of a major research university? In both regions, regional actors other than higher education institutions played significant roles in the evolution of the industry. These actors played the role of 'surrogate universities' by creating a skilled labour pool, knowledge, and entrepreneurial startup companies (Mayer, 2003). The following will outline the growth dynamics of each region's high-tech economy.

Portland: Firms Grow the Silicon Forest

In the Portland region, a high-technology industry cluster evolved without a world-class engineering and computer science research university. Oregon's main research universities are located outside of metropolitan Portland and are scattered around the state. Portland State University is the metropolitan area's major public university and boasts the largest student body in the state. It ranks in the fourth tier of research universities in the United States and has not contributed significantly to regional high-technology growth. The seven other higher education institutions in the region are rather small.[2] If the existing institutions have not influenced economic development, how then was Portland able to root a high-technology economy?

In Portland, two high-tech firms in particular have played a prominent role in growing the high-technology industry. These firms are Tektronix and Intel. Tektronix began as a Fordist-type high-technology firm in 1946 and Intel opened a branch plant in 1976 and evolved into a post-Fordist

[2] The University of Oregon is located in Eugene, which is about 100 miles South of Portland. Oregon State University is located in Corvallis, a small town about 50 miles South of Portland. The seven small institutions in Portland are Reed College, Concordia University, University of Portland, Linfield College, George Fox University, Pacific University, and Lewis and Clark College.

manufacturing operation that is heavily dependent on suppliers and subcontractors.

Tektronix is a homegrown company that was started by local entrepreneurs during the post-war period to manufacture, test and measurement instruments (oscilloscopes). The company began with moderate growth but soon gained increased market share and, as a result, would grow in size and scope (Lee, 1986). Ten years after Tektronix was founded, the number of employees exceeded 1000 and by 1980 the company employed 16,405 people. Portland's high-technology industry began to grow in the late 1970s, primarily as a result of the phenomenal growth of Tektronix. Portland would later diversify with Intel's arrival and dependence on a networked industry cluster. In 1981, for example, the region had 32,831 high-tech employees. This number increased to 64,891 in 2000.

From the beginning, Tektronix represented a vertically integrated company and combined corporate functions such as manufacturing, research and development, marketing, training and education. Over time, Tektronix also diversified into many different technology and product fields, which were often unrelated to its core product, the oscilloscope. Concerns for product quality and the lack of regional suppliers provided the rationale for this vertically integrated organisation pattern. In addition, Tektronix's growth contributed to the creation of a skilled labour pool in a region that did not possess much high-technology employment. Inside Tektronix, engineers found a very supportive work environment that offered them many opportunities for skill development and training (Lee, 1986). Some interviewees noted that Tektronix was a 'great finishing school'. An extensive corporate education programme—Tektronix Education Program (TEP)—rivaled most local community colleges and, from the 1940s to the late 1970s, Tektronix contributed to the development of a specialised and highly skilled regional labour market. Most employees were attracted from other areas in the United States and came to Portland to work for Tektronix. Many of them were also hired from the nation's top academic institutions, which illustrates the arm's length relationships Tektronix had with higher education institutions outside the region.

In the area of knowledge creation and innovation, Tektronix played an important role in the evolution of the Silicon Forest. In the late 1970s, the company decided to establish a research and development laboratory, which was commonly known as Tek Labs (Lee, 1986). Tek Labs was similar to what Xerox created with Xerox Parc in Silicon Valley (Smith & Alexander, 1988; Florida & Kenney, 1990). Tek Labs represented a separate unit within Tektronix where researchers conducted basic and applied research in a variety of fields. PhD level researchers were employed and created breakthrough innovations. However, the problem with the laboratory was that it was functionally separate from the rest of the company and the transfer of innovations and technologies created in the laboratory to the rest of the company presented problems. Management also often did not understand the significance of the lab's innovations and cancelled projects at the last minute. Tek Labs in the end experienced the same fate as Xerox Parc and turned into a ‘generic development lab’ (Florida & Kenney, 1990) for the region because many researchers left and established their own companies to commercialise the innovations they created. In 1995, Tektronix abandoned Tek Labs and integrated advanced research and development within its product and business lines.

During the early 1980s Tektronix began to experience troubling times primarily because of larger macro-economic changes and declining market share. Tektronix restructured by laying off employees, divesting business units, and integrating corporate functions. The company shed more than half its workforce (16,025 jobs) from 1985 to 1995, and by 2005 employed only 4,334 worldwide. As a result of Tektronix’s restructuring, the region experienced a surge in entrepreneurship.

Through a survey of the genealogy of high-technology firms, I examined the extent to which Tektronix functioned as an incubator for the region. Between 1948 and 1979 (Tektronix’s Fordist period), Tektronix spawned 12 start-up companies. These companies in turn functioned as incubators themselves and another 12 companies can trace their roots to these Tektronix start-ups. After 1980, entrepreneurial dynamics in Portland changed dramatically, primarily as a function of Tektronix restructuring. Tektronix spawned an additional 48 companies between 1980 and 2000. These companies in turn were incubators for an additional 23 firms (Tektronix grandchildren and grand-grandchildren). Some of these firms have become suppliers and contractors to Tektronix, others developed successful business models on their own. The post-Fordist period after 1980 represented an important time for Portland because the region developed a critical mass of small and medium-sized firms.

During the time when Tektronix functioned as a wellspring of entrepreneurial activity, Portland experienced another corporate infusion. In 1976, Intel moved its first branch operation to the Portland metropolitan area. Initially the branch plant was a mere manufacturing site (flash memory chips). Over time, however, Intel began to establish research and development operations in the region. In early 2006, Intel employed about 15,500 employees in Oregon and operated on seven sites throughout the region. Intel’s evolution from a manufacturing to a complex research and development operation is evidenced in the growth of its patent registrations. Oregon-based Intel employees registered 1,301 patents between 1979 and 1999. This represents 41% of all patents issued in the Portland region. Moreover, Intel’s average annual patent growth in Portland significantly outpaced Intel’s patent growth in California: average annual growth rate for Intel patents in Portland between 1979 and 1999 was 27% as compared with a rate of 17% for patents issued by California-based inventors. During the two-year period between 1996 and 1998, Intel’s Oregon inventors issued more patents than in any other location. These trends illustrate the strategic importance of Portland as a high-tech location for Intel, but they also illustrate that Intel has played an important role as a ‘regional innovation organiser.’

Compared to Tektronix, Intel has not played such an important role as an incubator for entrepreneurial firms. From 1977 to 2000, Intel spawned 38 companies. There are also important differences between Tektronix and Intel regarding their influence on labour in the region. Tektronix's extensive education programme and its arm's length relationships to the nation's academic institutions ensured the attraction and retention of skilled labour. Intel functioned primarily as a labour magnet during its growth period in the 1990s. The firm primarily imports labour from outside (according to one executive, between 70 to 80% of Intel's hires are from outside Oregon). In addition, Intel's efforts in education and training are very focused and narrow in scope. The company augments its courses by using the locally available higher education infrastructure. At Intel, in-house courses are offered through the Intel University and are directed towards the company's direct needs. Intel also selectively uses local higher education institutions such as the OGI School of Science and Engineering for offering advanced technical classes. Local institutions such as OGI benefit from such close relationships as more than two thirds of tuition reimbursements Intel gave out in 2000 went to the school.

In contrast to Tektronix, Intel never established a separate R&D laboratory. Rather, Intel integrates research and development within the manufacturing process in the so-called development fabrication plants. Cutting-edge semiconductor manufacturing capabilities are developed within these plants at the mass volume level. Once the process is perfected the development facility is turned into a regular manufacturing plant. In addition, Intel is not vertically integrated but subcontracts for services and supplies extensively. Competitors, suppliers and subcontractors began to move to the region to establish a presence in close proximity to Intel, in effect contributing to the development of a regional high-technology industry cluster (Cortright & Mayer, 2000).

Tektronix and Intel have played important roles as 'surrogate universities' in the growth of the Silicon Forest (Mayer, 2005b). While Tektronix's restructuring efforts from a Fordist to a post-Fordist corporation seeded the region with many spin-off companies, Intel's role as a post-Fordist anchor of a networked semiconductor industry cluster ensured the continued growth of the region. Over time, the region was able to establish an innovation milieu that is characterised by a critical mass of start-up companies, related firms that function as suppliers and subcontractors, and competitors. Support services such as lawyers, specialised public relations firms, and locally based venture capitalists emerged as well. In addition, state and local governments responded to the growth of the high-technology industry primarily by establishing tax incentive programmes for capital-intensive high-tech firms such as Intel to ensure continued investments. In addition, the region's higher education institutions are responding to the growth of the industry, as will be discussed in the following sections.

Washington, DC: Federal Government Nurtures IT Sector

The Washington, DC region features many similarities to the Portland region regarding the role of higher education in regional economic development. Like in Portland, DC's major universities have not significantly contributed to high-technology economic success (Markusen *et al*., 1991; Feldman, 1994; Feldman & Desrochers, 2003). The region's main universities are the Johns Hopkins University in Baltimore, Maryland, George Mason University, and the University of Maryland at College Park, Georgetown University, Howard University and George Washington University.[3] In addition, various universities from around the United States established research and development laboratories in the region (Greater Washington Initiative, 2003), perhaps to leverage the proximity to federal government agencies such as the National Institutes of Health or the National Science Foundation.

In a series of articles, Maryann Feldman and her colleagues (Feldman, 1994; Feldman & Desrochers, 2003, Forthcoming) have examined Johns Hopkins University's influence on regional economic development. They found that the university 'had not generated highly visible economic benefit for the local area.' (Feldman & Desrochers, 2003, p. 20) As reasons, they cite the university's lack of an economic development objective and the associated lack of incentives and encouragement for commercial activity. They speculate that the type of research—which was basic in nature—may be less amenable to direct technology transfer. In addition, earlier work by Feldman (1994) presents evidence that the benefits associated with the presence of Johns Hopkins University were not leveraged by the local area because an innovative regional infrastructure did not exist. The absence of such regional innovation infrastructure was also the reason why Cleveland, for example, was not able to leverage the knowledge and innovation creation in the locally based laboratories (Fogarty & Sinha, 1999).

While there is plenty of evidence that the Washington, DC region has not leveraged its higher education institutions, the question remains how the region's high-technology industry evolved. In their analysis of the biotechnology industry in the Washington, DC region, Feldman & Francis (2003, p. 766) posit that 'the Capitol region biotechnology cluster, in essence, is the result of three sets of important factors: pre-existing resources, entrepreneurship and incentives and infrastructure provided by government.' Feldman & Francis point to a series of critical exogenous influences that sparked the emergence of entrepreneurial activity in the region. The first was the passage of two policies (the Stevenson–Wydler Technology Innovation Act and the Bayh–Dole University and Small

[3] Markusen *et al*. (1991, p. 214) state that in the Washington, DC region 'unlike in southern California and Massachusetts, university research has played little part in the rise of this region. George Mason and George Washington universities have recently expanded their electronics programs, but this has occurred in response to demand, not the other way around.'

Business Patent Act) that allowed federal and university laboratories to license and patent their innovations. This in turn provided increased incentives for scientists in these laboratories to start their own companies. Second, the Small Business Innovation and Research program (SBIR) was created in 1982 and provided a significant financing resource for small businesses. Third, changes in federal government employment conditions contributed to increased entrepreneurship. In particular, 'federal downsizing and switch to outside contracting that began under the Carter Administration, provided an additional push for scientists and engineers to take opportunity of the technology developed in their government laboratories, and license it to start-ups' (Feldman & Francis, 2003, p. 781). In their seminal work on the spatial implications of the military industrial complex, Markusen *et al*. (1991) describe Washington, DC's evolution as a high-tech region as the 'tertiarization of the defense industries.' They assert that DC benefited from the development of a research complex without attendant manufacturing. They state that 'in an earlier era of defense-industry building, military procurement followed the concentration of existing expertise, whether in the laboratories of major technical universities [...] or in the manufacturing companies. [...] Now these companies or their successors beat a path to the national capital' (Markusen *et al*., 1991, p. 214). Increased complexity and specialisation in the budget and procurement process required federal contractors to be near federal agencies. This explains the continued persistence of spatial agglomerations of federal contractors—often high-technology service businesses—in the Northern Virginia suburbs along the Dulles corridor (which includes the suburban office markets—often also referred to as edge cities (Garrau, 1992)—of Reston, Herndon and Tysons Corner).

These exogenous factors contributed to the emergence of knowledge-based start-up companies that often had contractual or funding ties with the federal government. As a response to this increased economic development activity in the DC region, state and local government as well as universities began to adapt and devise mechanisms to support economic development (i.e. the creation of incubator facilities, financing of start-ups, targeted education programs and degrees, etc). Feldman & Francis (2003, p. 783) state that 'networks of entrepreneurs, policy-makers, and secondary industry contractors sprung up; universities, colleges and technical centres recognized the need for high-tech trained personnel and offered programmes to satisfy that demand.' In other words, once the region experienced some level of entrepreneurship, other economic development activity followed.

In the case of Washington, DC, government institutions played an important role in the formation of a high-technology economy. Feldman & Francis (2003) present evidence that the earliest biotechnology entrepreneurs emerged from government-related research and development laboratories such as Walter Reed Army Institute for Research (WRAIR) and the National Institute of Health (NIH): 'at least 45 biotech entrepreneurs who were previously employed at the NIH have started companies in the state of Maryland.' (Feldman & Francis, 2003, p. 771)

As in the case of Portland, employee layoffs energised the region's entrepreneurial environment. Elsewhere, Feldman (2001) describes how federal downsizing and outsourcing affected the region's economy beginning in the 1970s. Beginning with the Carter administration, federal government began laying-off employees and decreasing levels of pay. Both of these trends led individuals to leave federal employment and to start their own companies. In addition, federal government sought to outsource and subcontract services. This in turn provided these entrepreneurs with viable business options.

Outsourcing and federal procurement continues to play an important role in the Washington, DC region. These trends are fueled by efforts against terrorist attacks, resulting from the attacks on September 11, 2001. Federal procurement for homeland security products and services, for example, almost tripled in the four years from 2001 to 2004, and Washington, DC captured 51.9% ($2.77 billion) of the nation's total procurement in homeland security in 2004 (Mayer, 2005a).

Similar to Portland, a negative exogenous event—federal downsizing and outsourcing—contributed positively to the region's emergence as a post-Fordist high-technology economy. In the case of DC, the federal government functioned as a 'surrogate university' for the region because federal agencies adopted a post-Fordist strategy—i.e. subcontract and interact with corporations in procurement networks. University involvement—mainly in the form of educational offerings and labour provision—followed and responded to high-technology growth dynamics.

Regional Answers: Supporting Research and Linking to Industry

Both regions have developed university-based economic development efforts to react to a growing regionalised high-technology economy and to compensate for the absence of a strong scientific research university. In both cases, local leaders are trying to bolster existing higher education institutions and link them to industry.

For the Washington, DC region, such efforts concentrate on the Virginia side of the metropolitan region. This may be the result of the strong presence of a high-technology service industry in that part of the metropolitan area. In contrast to Virginia, the Maryland part of the Washington, DC metropolitan region may not perceive the lack of a major research institution because it boasts a significant biotechnology industry with strong ties to the National Institutes of Health and the Johns Hopkins University (Cortright & Mayer, 2002).

In a series of state reports, political leaders recognised the gaps in higher education resources in Virginia (State Council of Higher Education for Virginia, 2002; Virginia Research & Technology Advisory Committee, 2003a, 2003b). The reports acknowledge that Virginia lags behind many other states in terms of higher education research funding and expenditures. One of the reports states that 'Virginia's research universities are not located near Virginia's technology businesses' and goes on to say that 'this places both the university and the technology businesses at a distinct and structural competitive advantage' (Virginia Research & Technology Advisory Committee, 2003a, p. 4).

The main universities that are located in the Virginia part of the Washington, DC metropolitan region are George Mason University (GMU) and George Washington University (GWU). In the following, I will focus on the efforts George Mason is undertaking in establishing a science and engineering oriented branch campus in an outer suburb of the DC region. George Mason University started as a satellite campus of the University of Virginia in 1957. The institution moved to its main campus in Fairfax County in 1958 and became an independent member of the Commonwealth's system of colleges and universities in 1972. Beginning in the late 1970s, GMU established other campuses and followed the model of the so-called 'distributed university.' Its Arlington County campus and a campus in Manassas, which is part of Prince William County, are part of this satellite model. GMU's Manassas campus opened in 1997 and is located at the county's 2,000 acre business park which is called Innovation@Prince William.[4] (George Mason University, 2004) The Prince William campus primarily focuses on high-technology/biotechnology and emphasises bioinformatics, biotechnology, forensic biosciences, computer and information technology. Several high-technology companies (Mediatech, GEO-CENTERS Inc.) have moved to the area and noted the potential opportunities to work with GMU researchers and students (Brubaker, 2004). George Mason University provides the academic anchor within Prince William County's economy. In contrast to more close-in locations in the DC area, Prince William County benefits from available industrial land to attract high-technology companies. In addition, state and local government have contributed with financial incentives to attract private industry and repeatedly tout the benefits of the university.

Another example for supporting academic research and development is the proposed Howard Hughes Medical Institute (HHMI), slated to open in 2006 in Loudoun County. The plans call for a $500 million investment in laboratory research facilities and housing. Research at the institute will focus on bioinformatics and genomics; plans are to employ a total of about 300 employees (Chea, 2001). Local economic development officials expect that the HHMI will function as a magnet for other high-technology companies (much like GMU) and that spin-off companies will develop (Joyce, 2002).

For the Washington, DC region, some critics have questioned whether efforts will contribute to the creation of a culture of entrepreneurship and

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[4] In 1996, Prince William County began to acquire land for the business park and named the area Innovation@Prince William. The sector plan for the area provides for a hotel, conference center and high technology businesses (Kittower, 1997).

commercialisation. *Washington Post* reporter Pearlstein, for example, writes that the region was successful in creating a 'scientific culture more oriented toward winning research grants and appropriation than toward starting companies' (Pearlstein, 2004, p. E01). Nevertheless, the efforts on behalf of George Mason University and the proposed Howard Hughes facility indicate that higher education institutions are responding to high-technology economic growth and are engaging in triple helix relationships with local government and industry. Furthermore George Mason University represents a young university that experienced growth only in the last three decades. Its location in a core high-technology area allowed the school to reorient new investments towards local industry.

Similar to Virginia's efforts, Oregon is trying to bolster its higher education institutions. Most notable is the creation of the Oregon Nanoscience and Microtechnology Institute (ONAMI). Its genesis was in 2000 with a collaboration between the University of Oregon and Oregon State University—both of which are located outside of the Portland region—and has since then expanded to include Portland State University, the Pacific Northwest National Laboratory (located in Southeastern Washington State) and Oregon Health & Science University (Oregon Business, 2004). For the first time in the region's higher education history, all major research universities are collaborating on a joint project. ONAMI received $21 million from the state and is aggressively pursuing federal funding opportunities. The institute's goal is to conduct applied research in multi-scale materials and devices and connect this with existing industry strengths in the state. Partnering with industry and helping the region's business community are primary goals. This is also evidenced in the location of the institute: ONAMI is co-located with the Hewlett-Packard facility in Corvallis, Oregon, which is about 85 miles south of Portland, the main location of Oregon's high-technology industry. However, the institute retains strong ties to Portland's high-tech industry.

ONAMI's organisational structure involves close relationships with industry by incorporating venture capitalists and industry representatives on its advisory board. The initial push for creating the organisation came from a state-level advisory body, the Oregon Council for Knowledge and Economic Development, which was established in 2001. The Council represented the public sector and private industry and recommended the establishment of so-called 'signature research centers' (Oregon Council for Knowledge and Economic Development, 2002). The most avid supporters of the signature research center were industry representatives. In particular, prominent local venture capitalists and large high-technology firms such as Hewlett-Packard, Tektronix and Intel lobbied for the creation of the research centre and argued that applied research rather than basic research can ensure regional economic competitiveness. The research centre fits closely with the corporate expertise these firms have and can augment their research and development efforts.

It seems that ONAMI is a classic example of the triple helix at work: In this case, however, industry provided political support for the research centre. Universities responded through a networked approach to the issue. The network model is aimed at leveraging synergies among existing institutions in a region that does not possess one individual world-class research organisation. State and local government are actively supporting ONAMI in terms of both financial contributions and strategic planning. For example, various state and local economic development strategies included higher education efforts such as ONAMI as strategic targets and goals.

Conclusion: Triple Helix at Work

The theory of the triple helix conceptualises the university's role in the 'commodification of knowledge' (Boucher *et al.*, 2003) through technology transfer, licensing agreements, technology parks, and spin-off firms. In contrast to the ivory tower model of the past, higher education institutions have become 'entrepreneurial universities' (Etzkowitz *et al.*, 2000). The various functions—traditional and new—of the university are summarised in Table 2, which is adapted from Luger & Goldstein (1997). Most new activities that universities are engaged with are aimed at increasing a region's economic competitiveness and higher education institutions are seen as engines of growth.

Common to these conceptualisations is the notion that there is a linear relationship between the university and its regional economy. However, as we have seen from the discussion of the case of Portland and Washington, DC, there might also be a reverse relationship of industry influence on higher education institutions. While the cases of Portland and Washington, DC confirm the theory of the triple helix of university–industry–government partnerships, the analysis also allows for assigning directionality to the evolution of the triple helix. Portland and Washington, DC illustrate that in regions without significant research universities but where processes of post-Fordist restructuring have created regional innovation systems, higher education institutions respond to industry needs with efforts to integrate and link with industry. Furthermore, state and local governments provide important support for these linkages and continue to play an essential role in the competitiveness of these regions.

Etzkowitz (2001) describes four dimensions that define the triple helix. The first dimension is the internal transformation of each individual element of the triple helix (i.e. industry, government, university). Firms, for example, have become more reliant on local higher education institutions—as in the case of Intel in Portland—and utilise them for their training and research needs. They turn to higher education institutions in their own back yards instead of just relying on arm's length relationships to distant national institutions. Higher education institutions are responding to the needs of industry and are leveraging state support to provide and adjust their offerings to regional needs (as is the case with ONAMI in Oregon). Lastly, state and local governments are reacting with financial support and

Table 2. New and traditional roles of the university in regional economic development

Activity	Description	Traditional or new?
Knowledge creation via research	Creation of basic knowledge through research	Traditional
Human capital formation	Knowledge transfer from faculty to student Students are the supply of talented and skilled workforce	Traditional
Transfer of know-how	Application of knowledge to the improvement of existing products and processes	Traditional, New
Technological innovation	Application of knowledge to the creation and commercialisation of new products	Traditional, New
Capital investment	Creation of physical capital and infrastructure	Traditional, New
Regional leadership	Leadership in addressing critical social and economic problems	New
Knowledge infrastructure	Support services for other economic actors	New
Regional milieu	Creation of a favorable environment	Traditional

Source: Typology adapted from Luger & Goldstein (1997) strategic action plans and hope to increase regional economic competitiveness in a globalising knowledge-based world. Thus, the case studies show how each institution in the triple helix adjusts themselves to a changing environment.

Another dimension Etzkowitz describes is the nature of the relationships between the constituents of the triple helix. Increasingly, universities, industries, and government are dependent on each other. This is particularly evident in the creation of research centres—as is the case in DC and Portland. These research centres are intended to respond and fit to regional industry needs (OECD, 1999). All sides—industry, university, government—see their involvement with theses centers as win-win arrangements. Universities will gain corporate support for their research, which is increasingly important in the light of declining federal and state support. Industry is able to 'outsource' applied and basic research and can further concentrate on core business. As the case of Tektronix and Intel has shown, industry is less likely to have in-house research and development laboratories and they have come to rely more on partnerships with higher education institutions. State and local governments are becoming dependent on these relationships because they can ensure regional embeddedness of firms and economic viability in the future.

The theory of the triple helix, however, does not provide us with an answer about the strength and magnitude of engagement of higher education institutions with their region. The theory merely describes processes of transformation and interaction among industry actors, government agencies, and universities. Taking the theory further and making it relevant to the analysis of the role of the university in high-technology regional development, we may want to draw on work about the 'tiers of engagement' of universities (Boucher *et al*., 2003).

This work allows for the differentiation of types of university-region engagement. Boucher *et al*. propose four tiers of engagement and stratify the differences by the nature of the region and the character of the university. They describe the single player university in a peripheral region and highlight its close linkages to the region's development that are primarily due to being the 'only game in town.' For the US context, the phenomenon of the land grant university located in a small town with its extension services reaching out beyond its jurisdiction represents this model.

The second level of engagement is associated with the multi-player universities in peripheral regions. Here, a variety of universities are located within a region and their involvements are less clear cut than in the previous case. The third case is associated with the traditional university in core regions. Boucher *et al*. found that these core regions are usually seats for national governments, and local universities are less engaged in local development but more oriented towards the national or even international scale. This may have been the case in the Washington, DC region. In this region, high-technology development may have needed to achieve a critical mass and necessary magnitude first, to entice

Table 3. Nature of high-tech economy and university engagement

Nature of high-tech economy	University engagement: Pro-active university involvement	University engagement: Reactive university involvement
High-tech service economy	*Additional research is needed to find appropriate cases*	Washington, DC
High-tech manufacturing economy	Austin, Texas	Portland, Oregon
High-tech service & manufacturing economy	Silicon Valley Boston's Route 128	*Additional research is needed to find appropriate cases*

a response from local universities in terms of their economic development engagement.

The last category Boucher *et al*. describe, is the case where a newer technology-oriented university has evolved in a core region. These universities resorted to marketing themselves as regionally engaged institutions and their emphasis is on contributing to regional economic development. For Portland, we can observe more engagement by the newer local universities in response to the evolution of the regional high-technology industry. In the case of DC, George Mason University has become one of these newer regionally engaged institutions.

Boucher *et al*.'s framework provides for a useful analysis of the influence of industry on universities. Their framework will also advance the triple helix model because it provides a way to assess the magnitude of engagement. Table 3 outlines different tiers of engagements and highlights areas for additional research, in particular for high-technology regional development.

The positive impacts of the regional triple helix in Washington, DC and Portland will depend on a couple of factors. Both regions need to recognise the important role higher education institutions play for the creation and maintenance of a specialised high-technology labour market, knowledge creation, technology transfer, and entrepreneurship. This is an important aspect for policy making for these particular regions because their evolution as high-tech centres happened despite the absence of a world-class research university. One could argue that they do not need universities because they were able to become competitive without them. However, for future expansion of industry, they are necessary. Universities play an important role as supporting institutions in regional innovation systems. In addition, universities engage with regional culture and sports, they provide educational opportunities for various groups, they conduct outreach and community services, they can act to increase a region's image, etc. Thus, their support not only advances regional economic competitiveness, but also broader community development goals.

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References

Archibugi, D. & Pianta, M. (1996) Innovation surveys and patents as technology indicators: the state of the art, in: OECD (Ed.) *Innovation, Patents and Technological Strategies* (Paris: OECD).

Atkinson, R. D. & Gottlieb, P. D. (2001) *The Metropolitan New Economy Index. Benchmarking Economic Transformation in the Nation's Metropolitan Areas* (Washington DC: Progressive Policy Institute).

Boucher, G., Conway, C. & Van Der Meer, E. (2003) Tiers of engagement by universities in their region's development, *Regional Studies*, 37(9), pp. 887–897.

Braczyk, H.-J., Cooke, P. & Heidenreich, M. (1998) *Regional Innovation Systems: The Role of Governance in a Globalized World* (London: UCL Press).

Brubaker, B. (2004) Biotech firm building in Prince William, *The Washington Post*, June 30, p. E05.

Castells, M. & Hall, P. (1994) *Technopoles of the World: The Making of 21st Century Industrial Complexes* (London: Routledge).

Chapple, K., Markusen, A., Schrock, G., Yamamoto, D. & Yu, P. (2004) Gauging metropolitan 'High-Tech' and 'I-Tech' activity, *Economic Development Quarterly*, 18(1), pp. 10–29.

Chea, T. (2001) Building the 'Bell Labs' of biology, *The Washington Post*, February 1, p. E05.

Cortright, J. & Mayer, H. (2000) *The Ecology of the Silicon Forest* (Portland, OR: Institute for Portland Metropolitan Studies, Portland State University).

Cortright, J. & Mayer, H. (2001) *High Tech Specialization: A Comparison of High Technology Centers* (Survey Series) (Washington, DC: The Brookings Institution).

Cortright, J. & Mayer, H. (2002) *Signs of Life: The Growth of Biotechnology Centers in the U.S.* (Washington DC: The Brookings Institution).

Cortright, J. & Mayer, H. (2004) Increasingly rank: the use and misuse of rankings in economic development, *Economic Development Quarterly*, 18(1), pp. 34–43.

Crevoisier, O. & Maillat, D. (1991) Milieu, industrial organization and territorial production system: towards a new theory of spatial development, in: R. Camagni (Ed) *Innovation Networks: Spatial Perspectives* (London: Belhaven Press).

DeVol, R. C. (1999) *America's High Tech Economy: Growth, Development and Risks for Metropolitan Areas* (Santa Monica, CA: Milken Institute).

Etzkowitz, H. (2001) The entrepreneurial university and the emergence of democratic corporatism, in: H. Etzkowitz & L. Leydesdorff (Eds) *Universities and the Global Knowledge Economy: A Triple Helix of University-Industry-Government Relations*, pp. 141–152 (New York: Continuum).

Etzkowitz, H. & Leydesdorff, L. (1995) The triple helix of university-industry-government relations: a laboratory for knowledge based economic development, *EASST Review*, 14(1), pp. 11–19.

Etzkowitz, H. & Leydesdorff, L. (2001a) Introduction: Universities in the global knowledge economy, in: H. Etzkowitz & L. Leydesdorff (Eds) *Universities and the Global Knowledge Economy: A Triple Helix of University-Industry-Government Relations*, pp. 1–8 (New York: Continuum).

Etzkowitz, H. & Leydesdorff, L. (2001b) *Universities and the Global Knowledge Economy: A Triple Helix of University-Industry-Government Relations* (New York: Continuum).

Etzkowitz, H., Webster, A., Gebhardt, C. & Terra, B. R. C. (2000) The future of the university and the university of the future: evolution of ivory tower to entrepreneurial paradigm, *Research Policy*, 29, pp. 313–330.

Feldman, M. (1994) The university and economic development: the case of Johns Hopkins University and Baltimore, *Economic Development Quarterly*, 8(1), pp. 67–76.
Feldman, M. (2001) The entrepreneurial event revisited: firm formation in a regional context, *Industrial and Corporate Change*, 10(4), pp. 861–891.
Feldman, M. (2003) The locational dynamics of the US biotech industry: knowledge externalities and the anchor hypothesis, *Industry and Innovation*, 10(3), pp. 311–328.
Feldman, M. & Desrochers, P. (2003) Research universities and local economic development: lessons from the history of the Johns Hopkins University, *Industry and Innovation*, 10(1), pp. 5–24.
Feldman, M. & Desrochers, P. (Forthcoming) Truth for its own sake: Academic culture and technology transfer at Johns Hopkins University. Minerva.
Feldman, M. & Francis, J. (2003) Fortune favors the prepared region: the case of entrepreneurship and the Capitol region biotechnology cluster, *European Planning Studies*, 11(7), pp. 765–788.
Florida, R. & Kenney, M. (1990) *The Breakthrough Illusion: Corporate America's Failure to Move from Innovation to Mass Production* (New York: Basic Books).
Fogarty, M. S. & Sinha, A. K. (1999) Why older regions can't generalize from Route 128 and Silicon Valley: university-industry relationships and regional innovation systems, in: L. M. Branscomb, F. Kodama & R. Florida (Eds) *Industrializing Knowledge: University-Industry Linkages in Japan and the United States* (Cambridge, MA: MIT Press).
Garrau, J. (1992) *Edge City: Life on the New Frontier* (New York: Doubleday).
George Mason University (2004) About the Prince William Campus. George Mason University. Retrieved October 10, 2004, from the World Wide Web: http://princewilliam.gmu.edu/about.html.
Gray, M., Golob, E. & Markusen, A. (1996) Big firms, long arms, wide shoulders: the 'hub-and-spoke' industrial district in the Seattle region, *Regional Studies*, 30(7), pp. 651(616).
Gray, M., Golob, E. & Markusen, A. (1999) Seattle: a classic hub-and-spoke region, in: A. Markusen, Y.-S. Lee & S. DiGiovanna (Eds) *Second Tier Cities: Rapid Growth beyond the Metropolis* (Minneapolis: University of Minnesota).
Greater Washington Initiative (2003) *Greater Washington Research & Development Facilities Directory* (Washington, DC: Great Washington Board of Trace).
Gulbrandsen, M. (2001) Universities and industrial competitive advantage, in: H. Etzkowitz & L. Leydesdorff (Eds) *Universities and the Global Knowledge Economy: a Triple Helix of University-Industry-Government Relations*, pp. 121–140 (New York: Continuum).
Harrison, B. (1992) Industrial districts: old wine in new bottles?, *Regional Studies*, 26(5), pp. 469–483.
Hirst, P. & Zeitlin, J. (1991) Flexible specialization versus post-Fordism: theory, evidence and policy implications, *Economy and Society*, 20(1), pp. 1–56.
Joyce, A. (2002) Making Loudoun a center for research, *The Washington Post*, March 28, p. LZ05.
Kittower, D. (1997) Innovation is centerpiece of Prince William success. *Washington Business Journal*, September 12.
Lee, M. M. (1986) *Winning with People: the First 40 Years of Tektronix* (Portland: Tektronix, Inc).
Leslie, S. W. (1993) *The Cold War and American Science: the Military-Industrial-Academic Complex at MIT and Stanford* (New York: Columbia University Press).
Leslie, S. W. & Kargon, R. H. (1994) Electronics and the geography of innovation in post-war America, *History and Technology*, 11, pp. 217–231.
Leslie, S. W. & Kargon, R. H. (1996) Selling Silicon Valley: Frederick Terman's model for regional advantage, *Business History Review*, 70, pp. 435–472.
Luger, M. & Goldstein, H. (1990) *Technology in the Garden* (Chapel Hill: University of North Carolina Press).
Luger, M. & Goldstein, H. (1997) What is the role of public universities in regional economic development?, in: R. Bingham & R. Mier (Eds) *Dilemmas of Urban Economic Development* (Thousand Oaks: Sage Publications).
Lundvall, B.-A. & Johnson, B. (1994) The learning economy, *Journal of Industry Studies*, 1(2), pp. 23–42.
Markusen, A., Hall, P., Campbell, S. & Deitrick, S. (1991) *The Rise of the Gunbelt: the Military Remapping of Industrial America* (New York: Oxford University Press).

Mayer, H. (2003) Taking root in the Silicon Forest: the role of high technology firms as surrogate universities in Portland, Oregon. Unpublished Dissertation, Portland State University, Portland, OR.

Mayer, H. (2005a) The homeland security industry and its impact on the Arlington, Virginia, economy [Issue Paper No. 7]. Arlington Economic Development. Retrieved November 21, 2005, from the World Wide Web: http://www.arlingtonvirginiausa.com/docs/homeland_security_short.pdf.

Mayer, H. (2005b) Taking root in the Silicon Forest: The role of high technology firms as surrogate universities in Portland, Oregon, *Journal of the American Planning Association*, 71(3), pp. 318–333.

Mayer, H., Holzheimer, T. & Glidden, H. (2005) Fostering emerging technology sectors in Arlington County: an economic development strategy for knowledge creation and innovation, *Economic Development Journal*, 4(1), pp. 7–17.

OECD (1999) The response of higher education institutions to regional needs. OECD. Retrieved April 4, 2006, from the World Wide Web: http://www.mszs.si/eurydice/pub/oecd/response.pdf.

Oregon Business (2004) Research Oregon: A special report on college and university research programs. Portland, OR.

Oregon Council for Knowledge and Economic Development (2002) Renewing Oregon's economy: growing jobs and industries through innovation. A report from the Oregon Council for Knowledge and Economic Development. Portland.

Pearlstein, S. (2004) Getting out of biotech's second tier, *The Washington Post*, September 8, p. E01.

Piore, M. & Sabel, C. (1984) *The Second Industrial Divide: Possibilities for Prosperity* (New York: Basic Books).

Porter, M. (2000) Location, competition, and economic development: local clusters in a global economy, *Economic Development Quarterly*, 14(1), pp. 15–34.

Progressive Policy Institute (2001) The Metropolitan New Economy Index. Retrieved June 27, 2006, from the World Wide Web: http://neweconomyindex.org/metro.

Saxenian, A. (1985) The genesis of Silicon Valley, in: P. Hall & A. Markusen (Eds) *Silicon Landscapes*, pp. 20–34 (Boston: Allen & Unwin).

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

Smilor, R. W., Gibson, D. V. & Kozmetsky, G. (1989) Creating the technopolis: high-technology development in Austin, Texas, *Journal of Business Venturing*, 4, pp. 49–67.

Smith, D. & Alexander, R. (1988) *Fumbling the Future: How Xerox Invented, then Ignored the First Personal Computer* (New York: William Morrow).

State Council of Higher Education for Virginia (2002) Condition of research at Virginia Colleges & Universities.

Virginia Research & Technology Advisory Committee (2003a) Report of the VRTAC Sub-committee on: the creation of new high-technology industries in Virginia.

Virginia Research & Technology Advisory Committee (2003b) Research & development strategies for the Commonwealth of Virginia: a report of the Virginia Research & Technology Advisory Commission.

Walcott, S. M. (2002) Analyzing an Innovative Environment: San Diego as a Bioscience Beachhead, *Economic Development Quarterly*, 16(2), pp. 99–114.

Walshok, M., Furtek, E., Lee, C. & Windham, P. (2002) Building regional innovation capacity: the San Diego experience, *Industry & Higher Education*, 16(1), pp. 27–42.