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# THE ECONOMIC BENEFITS

FROM INVESTMENT IN UNIVERSITY BASED  
RESEARCH, DEVELOPMENT AND EDUCATION



A NEW AMERICAN UNIVERSITY  
WHITE PAPER FROM THE  
**OFFICE OF THE PRESIDENT**  
ARIZONA STATE UNIVERSITY

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# THE ECONOMIC BENEFITS FROM INVESTMENT IN UNIVERSITY BASED RESEARCH, DEVELOPMENT AND EDUCATION

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This paper examines universities, particularly major research universities, as institutions engaged in integrated research, development and education (RD&E) activities. In surveying a range of literatures, this paper identifies and characterizes the variety of channels by which these institutions impact the regions in which they reside and the strategies that may be employed to develop and exploit these channels for regional economic development.

## I. Introduction

The relationship between investments in universities and economic development has been the subject of debate since the beginning of the Republic. This debate has repeatedly come to endorse increased and more specialized investment in American institutions of higher education and research – for more than 200 years. This debate has occurred not only at a national level, but also at a regional and local level, as citizens, policymakers and philanthropists have sought to elevate the existence of their small corner of the world. And, resulting from this debate, investments in universities have been made with the explicit goal of benefiting a region or locality, and have enjoyed profound success.

Every era has entered into this debate anew, often without an appreciation of the past. An extensive literature on the contributions of such investments to long-run economic growth has overwhelmingly affirmed the value of such investments as a macro-level (i.e., national) public policy tool. Yet, as we now occupy a new century, we must pause to appreciate the new circumstances faced by American research universities, and analyze how the benefits from additional investments could be garnered by the states and localities being asked to contribute. Formal quantitative analysis has been applied to both the general question of the value of university investments, as well as the specific impact of such investment on regions. Even though formal quantitative studies regularly affirm the value to regions of investments in universities, the narrow nature of such studies opens them to assault, and makes them less than useful for affirmative public policy design.

This paper examines the modern American research university as a multi-faceted institution engaged in research, development and education (RD&E) that is situated within a geographic context. While formal quantitative studies focus on narrow sets of well-specified inputs and outputs, this study will focus on a range of ‘channels’ through which benefits flow to a region (and the rest of the world) and strategies that can be employed to locally appropriate the returns from investments. The analytical case will be woven together with the obvious institutional/historical successes enjoyed by regions that have reaped the returns from their investment in university RD&E.

## II. The Research University as an Institution

Quantitative studies often do not fully appreciate the complexity of the research university as an institution. Such studies inevitably view universities in terms of inputs and outputs, without considering the context within which they evolve. Here we will explore the rise of science-based industry, the evolution of public and private American research universities, their co-evolution with various industries and technologies, and their contribution to regional and urban economies.

### **a. The Rise of Universities, Scientific Knowledge and Science-based Industry**

For hundreds of years, universities have incubated bodies of knowledge that have underpinned advances in technological capability, social organization, and industrial growth. During their formation in the 17th century, universities worked out the principles that since have guided scientific exploration and the harnessing of scientific knowledge for practical advantage. It was this grand orientation that focused the creative powers of many of the most intelligent men and women on unraveling the mysteries of nature. Without the emergence of the research university, science (and therefore, modern life) as we know it would not exist. Modern life profoundly depends upon the accumulated successes of these institutions, in ways we normally fail to recognize.

Universities have existed in various forms since the 13th century, but had little relation to modern concepts of science until they were transformed by the rise of independent scientific societies and academies and the norms of open scientific inquiry that they entailed (Guena, 1996). These organizations led to a transformation and revitalization of universities across Europe, and new models of teaching and research developed in Germany, England, and France (Ziman, 1984).

Under the broad logic of open science, a number of different strands of research universities took hold before 1850, each peculiar to its own national history (Dasgupta and David, 1994). England had Oxford and Cambridge, but it also had the Royal Institution of London that served as a center for both fundamental and applied scientific laboratory work in the Baconian tradition. France, under Napoleon, developed *Écoles* that were designed to support the development of a strong engineering class and bureaucratic class and to secure strength and capacity for empire building. The German research universities grew up as institutions encompassing the literature and philosophy of the Romantic period and strong theoretical and empirical work in the sciences. And, by this time, other European science centers had emerged.

A century before the founding of America's first research universities, the fruits of university-based scientific research were beginning to show. The development of mathematical tools was held in ten-

sion with studies of celestial mechanics and in 1776, Newton's Laws resulted. By the 1790s, processes for creating current electricity were discovered, and fundamental investigations into the nature and uses of electricity began. By the middle of the 1800s, university-based chemistry explorations were being undertaken in association with the German chemical industry. This and other work soon developed an empirical base to drive theoretical explorations that culminated in the creation of the periodic table, which fundamentally organized our knowledge about elements and their interaction, and the discovery of the atom and its structure, just before the turn of the 20th century. Quantum physics was developed upon this new knowledge about the existence, structure, and behavior of atoms. Investigations into cellular biology, from the late 1800s, intersected with bodies of organic chemistry knowledge, and spurred investigations on how characteristics were passed on in organisms through generations.

With only a brief review, we see how modern industrial societies could not exist without these bodies of knowledge. A necessary element for the development of these bodies of scientific knowledge was the presence of academic scientists who were motivated by the quest to push back the frontiers of knowledge.

Each of these discoveries spawned streams of scientific research and technological development that interacted over time, leading to the development of entire industries. These industries shaped modern life in fundamental ways. Electrification, chemical and dyestuff industries, electrochemicals, pharmaceuticals, telegraphy, telephone, radio, semiconductors, television, computers, nuclear power, aviation, numerical controlled machine tools, biotechnology, modern agriculture, and advanced materials were each fundamentally enabled by university science. These areas of knowledge have transformed not only our possibilities for industry, but also our understanding of human potential, our vision of our place in the world, and our expectations for the improvement of humanity and its surroundings.

### **b. A Short History of Public & Private Research Universities in the United States**

While the elite American colleges were built originally to educate gentlemen in the ways of theology, languages and the classics, they too were soon subjected to the powerful influence of this international scientific community (Rudolph, 1962; Veysey, 1965). America had little in the way of 'research' going on during this period. West Point (United States Military Academy) was a center of engineering excellence, but science had no place. Rensselaer Polytechnic Institute was established in the 1820s modeled on the French *Écoles*, but it did not embrace the sciences fully until it reorganized just before 1850. By the 1850s-60s, some 'scientific schools' were established within more traditional American colleges like Harvard, Yale and Columbia (Yale's was organized around applied chemistry; Harvard's

around zoology and botany; Columbia's around the fields related to mining). The scientific schools were hardly welcomed into these institutions, but they were widely emulated by other colleges over the 1850s and 60s, institutionalizing a home for science and engineering in American college curricula. These schools sewed the seeds for the later transformation of these institutions into research universities (Veysey, 1965; Geiger, 1986).

A wide range of formal and informal linkages between industry and universities were encouraged by the decentralized structure of the American university system, the reliance of many universities on state government funding, and the modest scope of this funding (Mowery and Nelson 1996).

American universities have long been largely concerned with providing vocational skills for employment in local industry. Research was closely associated with this training function and was defined by immediate, 'hands-on' practical problem solving for local firms (Geiger 1986). Much of this research was idiosyncratic, undertaken without a systematic disciplinary basis. This pattern was reinforced when by the early 1870s, Land Grant universities were established in many states under the Morrill Act of 1863 in support of agriculture and mechanical arts, bringing a distinctively American feel to higher education, with a direct link to questions of utility. It is also important to note that the establishment of these institutions was the primary factor driving in the geographic dispersion of scientific and engineering skills in America during this period (Ross, 1942).

As the Land Grant universities became a reality, another very powerful institutional model was introduced to the American university scene – the German research university. Aspects of the German research university were transferred to America with the establishment of Johns Hopkins in 1872. Germany's research universities had risen to clear prominence in chemistry, physics and agricultural sciences by this time. Johns Hopkins, and the American institutions that re-modeled themselves after it (Columbia, Harvard, Yale, Chicago), enabled America to host similar success in science and engineering over the next several decades.

Around the turn of the 20th century, university research and training started to differentiate itself from the particulars of industry practice and company projects. The new engineering and applied science disciplines, such as chemical engineering, electrical engineering and later aeronautical engineering, which emerged within American universities during this time, worked to develop a systematic basis for research and professional training (Rosenberg and Nelson 1994). These emerging fields of study sought to substitute generalizable knowledge for the idiosyncratic knowledge of industrial practice. For example, in chemical industry, much of the knowledge needed to build a plant was par-

ticular to a given chemical. Chemical engineering provided engineers with a set of generalizable principles that applied to all chemical processing, decreasing the amount of specific knowledge needed to build a particular plant (Hounshell and Smith, 1988).

These emerging disciplines, defined by programs of graduate studies with certified professional credentials, along with professional organizations and associated journals, underpinned the development of national communities of technically trained professionals with connections across universities, as well as between universities and industry. Their emergence was induced by and made possible the growing use of university-trained engineers and scientists in industry, and, in particular, the rise of the industrial research laboratory in the chemical industry and the new electrical equipment industry, and later throughout industry (see Hounshell and Smith, 1988; Mowery, 1981; Nobel, 1977; Reich 1985).

These new disciplines and training programs in American universities grew up in close connection to industry needs. At the same time, these disciplines laid the basis for an institutional division of labor between the universities and industry (Servos, 1980). Universities did research to produce generic knowledge to inform industry practice and research, while industry attended to the specifics of development and production (Hounshell and Smith, 1988; Reich, 1985).

While these disciplines have been concerned with fundamental research into process and product technologies, they also have played an important role in mediating the relationship between fundamental work in the sciences and industry problems (see Rosenberg and Nelson 1994). Developments in sciences not directly concerned with practical applications, such as physics and mathematics, found their way into industrial application through chemistry, electrical engineering, and other applied engineering disciplines. At the other end, engineers engaged with industry problems have posed important questions for disciplinary academic scientists.

The rise of science-based industry during the later part of the 19th century brought with it new patterns of economic development which were increasingly wedded to the evolving institutions of science, largely organized around universities. While each industry has its own story to tell, it is clear that all such industries could not have developed, or may not even have come into existence, without the presence of significant public investments in universities and complementary organizations. (Tucker, 1999)

American universities improved during World War I and between the wars. But, during and after World War II, American universities developed their scientific capabilities to be world leaders. After

WWI, it was well accepted by those in industry and government that university science combined with a much-enhanced industrial R&D contribution would be the key to the rise of American industry in the global context. But, it was World War II that spurred institutional growth for American science.

By the end of WWII, the US was left with a core set of research universities which were world leaders. In 1945, Vannevar Bush, the Director of the wartime Office of Scientific Research and Development identified California (Berkeley), Columbia, Yale, Harvard, Chicago and M.I.T. as the world-class research universities present in America. In his report to President Roosevelt, entitled *Science the Endless Frontier*, Bush called for a post-war federal commitment to science to strengthen these institutions (Bush, 1945). This commitment also enabled many other colleges and universities to enhance their research capabilities.

This top tier of schools remained largely the same with some new entrants. None of the top tier universities diminished as contributors to the world science base. But, the dispersion of federal funds developed an entire community of research universities. The American university system has evolved into a large, diversified system that serves the wide range of research needs posed by a modern industrial society. We now have more than 150 research universities in America, fulfilling different roles and contributing different knowledge products. The democratization of the American science establishment has been astounding with the rising tide of federal R&D funding raising a wide array of public and private research universities. In several cases, universities that did not exist or were still emerging in 1945 have risen to national prominence as research institutions, and have had profound economic development impacts on their respective regions (Graham and Diamond, 1997).

During the 1960s, dispersion was propelled by a massive expansion of inputs - research funds, faculty lines, and institutional capabilities. In the 1970s, dispersion occurred through residual growth in late-developing institutions, particularly in the Sunbelt. During the 1980s, growth and dispersion were prominent features of the U.S. academic research system. Total academic R&D expenditures grew from \$6.9 billion to \$12.5 billion (1982\$); dispersion occurred as the share of total research performed by the largest and most highly rated universities declined. Research funding expanded and scientists were in ample supply, but the relatively fixed numbers of faculty positions constrained research growth at distinguished universities. However, institutions in the next tier - those with fairly good infrastructure or settings - were able to increase research share in part by adding senior faculty, but more so by enhancing the productivity of existing positions. This dynamic also placed great pressure on institutions to find commensurate new resources for up-grading faculty lines and research settings (Geiger and Feller, 1995).

### **c. The Co-evolution of Industries, Core Technologies, and Supporting Institutions (such as Universities)**

As discussed above, the character and extent of technological opportunities enjoyed by industry are shaped institutionally. Discoveries and inventions resulting from the research of federally funded research institutes and university laboratories have directly affected the range of technological opportunities open to firms within an industry. Moreover, the scientific and technological societies that are often centered around universities, as well as the trade and technical associations that industries organize in order to share technological information, can also influence an industry's access to technological opportunities. In short, the technological opportunities open to an industry depend upon the institutions supporting scientific and technological advance as well as their diffusion.

The development of these institutions often is built on substantial public investments, private investments and R&D policies. These institutions shape the technological opportunities faced by an industry, as they support scientific advancement, foster and develop relevant applied scientific and engineering disciplines, develop fundamental technological solutions, accumulate and diffuse technological information and otherwise shaping the rate, character and direction of technological and industrial advance. (Tucker, 1999)

Scholars have dedicated substantial attention to this dynamic, and have provided us with frameworks for understanding it. Many excellent studies have helped us determine the factors that drive the rate, direction and character of technical change industry – and thereby, economic growth (Levin, Cohen, and Mowery, 1985; Cohen and Levin, 1989). And, related studies have helped us understand how these factors are shaped over time by the co-evolution of industries, technologies, and supporting institutions (Nelson, 1994; Nelson and Winter, 1982; Tucker, 1999)

Three key factors have been widely credited with driving technical change in industry: demand conditions, appropriability regimes (strategies), and technological opportunity. Many economists have long looked at demand as the primary, if not sole driving factor behind technical change (Kuznets, 1954, Schmookler, 1963). Other scholars have focused on the ability of a firm to appropriate the returns from their investment in R&D. Without adequate protections, some scholars say, firms will be led to under invest in innovative activity. Such scholars often identify patent rights as critical to innovators, though several other appropriability mechanisms have received attention, such as trade secrecy and lead-time.

Other scholars focus on the abundance of technological opportunities as the primary factor driving growth in an industry. They have shown that demand conditions are alone unable to induce technical advance, if technological opportunities are absent. They have shown also that the absence of any specific legal appropriability regime does not necessarily hinder innovators in all industries (Levin, Klevorick, Nelson, Winter, 1987). A number of industries largely forgo the use of patenting.

#### **d. The Contribution of American Research Universities to Regional Economies**

American research universities prior to WWII contributed powerfully to the growth of regions, even before receiving large-scale federal funding. After WWII, the rise in federally funded R&D enabled the development of increased concentrations of scientific and technical activities and the increased production of technical graduates. This funding supported the universities role in the rise of new fields and industries (e.g., biotechnology, semiconductors, optics, computers, etc.).

American research universities have not only served as the hub of the nation's science-based industry. They also have served as the source of regional technology clusters that have generated thousands of high-technology companies and billions of dollars. Route 128 and Silicon Valley are often cited in this regard, focusing on Harvard/MIT and Stanford respectively (Saxenian, 1994). Yet, there are other major instances of university-centered R&D activities underpinning regional advantage: San Diego (UCSD), Austin (UT Austin), Research Triangle (Duke, UNC, NCState), Rochester (URochester, RIT), to name a few.

There certainly are clusters of economic activity that are not based on university-centric knowledge networks, such as those based on natural resource endowments, sophisticated craft know-how, tradition, or merely local recruitment of high-tech firms (for the latter, see Malecki, 1987). Yet even many of these clusters are looking to university-based knowledge as a resource as they seek competitive advantages within globalizing sectors.

### III. Channels by Which University Investment Can Impact a Region

Much work concerned with explaining economic benefits of universities to regions is focused on knowledge spillovers. An important factor in explaining why these spillovers are “localized” or stay in the region is the tacit dimension of scientific and technical knowledge. This section discusses tacit knowledge, how it varies by sector, and over time. This section also considers three different, but related, channels through which tacit knowledge flows: 1) professional networks among professors and university-trained employees, 2) hiring by established firms, and 3) start-ups.

#### **a. Tacit Knowledge and the Tendency Toward Agglomeration (Clustering)**

A number of scholars have pointed to a paradox in the emergent importance of local proximity and geographic clusters precisely at a time when globalization seems to dominate economic activity (Porter 1990; Audretsch 1998). Panoply of factors such as telecommunications, transportation, immigration, and trade enabled the globalization of many aspects of corporate operations and supply chains. At the same time, leading developed countries have established new, knowledge-based comparative advantages. With knowledge generated and transmitted more efficiently via local proximity, economic activity based on new knowledge has a high propensity to cluster geographically (Audretsch 1998).

Tacitness refers to that aspect of knowledge that cannot be fully articulated or written down (Polanyi, 1967). The tacit dimension of technological knowledge consists of practical understanding based on experience that is embodied in persons and organizational processes (Nelson and Winter, 1982). Unlike information, tacit knowledge can only be communicated informally, typically through direct and repeated contact. Hence, in those cases where technology is defined by a high degree of tacitness, it will be slow to diffuse outside the organizations in which it was created (von Hippel, 1994; Zucker, et.al., 1998).

The tacit dimension of technological knowledge varies in importance by sector. Each sector is defined by a technological paradigm. That paradigm is constituted by the sector's core technologies, its industrial structure and supporting institutions, which 'co-evolve' (Nelson, 1995). Core technologies are defined as the technologies that underpin the business of a sector. Industrial structure refers to the number, size and structure of firms in an industry. Supporting institutions are institutions, such as universities and industry associations that support firms in the development of the sector's core technology or technologies.

Dosi (1988) argues that advances in a technical field are guided by technological paradigms. Technological paradigms define the problems to be solved and the tools, methods, and types of knowledge needed to solve those problems. Paradigms involve a mix of explicit knowledge (e.g., scientific and engineering principles and methods) and tacit knowledge (e.g. practical understanding of how things are done within a particular firm). The former is generally accessible to those trained in the relevant technical field (Dosi, 1988). The latter is often private and specific to a particular firm.

According to Dosi (1988), technological paradigms and the mix of knowledge they entail varies importantly with respect to a sector's core technology. In the case of machine tools, an important part of the knowledge base consists of tacit knowledge about the performance of previous generations of machines and the typical conditions of their use. By contrast, in some science-based sectors technical advance draws heavily on explicit scientific knowledge.

However, the mix of knowledge underpinning the development of a given technology may vary. The mix of tacit and explicit knowledge concerned in the development of a technology may be affected by firm strategy and supporting institutions.

Audretsch and Feldman (1996) found that industries in which knowledge spillovers are more prevalent have a greater propensity for innovative activity to cluster geographically than industries where these spillovers are less important. These innovative industries were more likely to cluster even when accounting for concentration of manufacturing locations in the industry.

Technology life cycle theory suggests that the mix of knowledge concerned in the advance of a given technology also varies with respect to the stage in its development. In particular, technology life cycle theorists argue that tacit knowledge is of relatively great importance during the early stage of a technology's development.

On the basis of case study evidence, Vernon (1960), the originator of the technology life cycle tradition, argues that during the introductory stage of the product life cycle, an important part of the innovation process involves the rapid exploitation of unexpected exchanges of ideas, which demands intense face-to-face interactions. Vernon does not speak of tacit knowledge *per se*, but his emphasis on the exchange of ideas depending on intense face-to-face interaction suggests the role of tacit knowledge.

Audretsch and Feldman (1996) draw on the work of technology life cycle theorists in a discussion of their research concerning the importance of proximity to innovative activity. They explain the role of tacit knowledge as follows:

...the propensity for innovative activity to cluster spatially will tend to be greatest in industries where tacit knowledge plays an important role. Because it is tacit knowledge, as opposed to information, which can only be transmitted informally, and typically demands direct and repeated contact. The role of tacit knowledge in generating innovative activity is presumably greatest during the early stages of the industry life cycle, before product standards have been established and before a dominant design has emerged (Audretsch and Feldman 1996).

The tacit dimension of scientific and technical knowledge provides the basis for localized spillovers, but does not ensure that a region can exploit this knowledge for advantage locally. This depends on a region's ability to create channels through which these spillovers will flow locally. Next we will consider three channels: social and professional networks among university faculty and university-trained workers, hiring of university students by existing firms, start-up companies launched by faculty and students.

### **b. Human Capital, Social Networks and Regional Workforces**

The human capital and social networks fostered by universities have repeatedly proven to play a pivotal role in regional economic development. Public land-grant universities were originally established in the 1870s to educate the sons and daughters of farmers and mechanics – of a specific state.

The literature strongly affirms that one of the most important contributions a university can make to the economic development of a region is local skills development through the graduation of high-quality, technically proficient alumni. A university does not merely offer educational services that are consumed by its citizenry just like any other public or private service. The process of higher education is the investment in people, and leads to the accrual of human capital. And, the process of higher education enables students to develop local networks and contacts that lead them to remain in the region. Both public and private universities play a critical role in regional economic development insofar as they cultivate social networks that serve as the basis for later economic action (Granovetter, 1973; Granovetter, 1985; Granovetter, et.al., 2000). It is these social ties that lead alumni to remain local, particularly if these ties lead to economic advantage.

In this sense, universities are important in attracting human capital to a local area and in stimulating entrepreneurial activity in the region. In particular, it is interesting that the attraction of post-graduate professional business and engineering students has been found to lead to their long-term relocation, suggesting the importance of academic institutions in the geographic pattern of agglomerations of footloose scientific firms, such as those in the Silicon Valley just south of San Francisco (Huffman, David, and Quigley, 2002). If managed correctly, universities serve as the basis for creating an environment supporting local innovative activity.

The development of such a local technical skill base, that complements the technology needs of local businesses, is one of the most critical roles of a university. And, this does not occur without the proper R&D facilities (and equipment) that enable the cultivation of hands-on practical proficiency in particular scientific and technical domains. The provision of such infrastructure for the cultivation of technical talent through active research programs is what universities do well (Florida, 1999; Feller, 1997; Storpor, 1995; Tasse, 1991). Not only do they enable the accrual of human capital within a region, but they also indirectly support the creation of technical teams that often come to function as 'quasi-firms' (Etzkowitz, 2003). Teams operating at the forefront of a field of science or technology, that are already highly motivated and competitive in the realm of peer-reviewed science, are often well-positioned to make the leap into early commercial activities in their domain of expertise.

Once this research infrastructure and these networks are established, they confer continued benefits upon the citizens and firms of a state. By fostering a higher level of inter-organizational collaboration than would otherwise occur, universities can enable networks of learning within technical industries that leads to more innovation and resiliency within a regional technology cluster (Powell, Koput, and Smith-Doerr, 1996).

These networks confer benefits to the region by contributing to the success of existing firms, enabling start-ups, and attracting established firms to the region. However, it is difficult to over-emphasize the importance of start-ups in the growth of these networks. Start-ups are a major source of localization, insofar as a region manages to influence entrepreneurs trained in the region to stay and put knowledge to use locally in new enterprises. Moreover, small enterprises (fewer than 500 employees) are more likely to exploit knowledge spillovers. Small firms are 50% more likely to follow university research than large firms (500+ employees) (Acs, Audretsch, and Feldman, 1994) and they benefit more from university research (Link and Rees, 1990). In the next section, we will turn to the range of organizations necessary to complement university based RD&E investments if local advantage is to be achieved.

### **c. Organizational Synergies and Agglomeration Economies**

Some regions host leading scientific research, but lack the requisite infrastructure to exploit knowledge spillovers effectively. Powell et al. (2002) point out the importance of complementary institutions and organizational synergies required for a region to benefit from local university-based scientific activity. These scholars were specifically interested in the role of venture capital organizations, and how the absence of such regionally focused capital undermined the ability of a region to capture the benefits from their university activities. Di Gregorio and Shane (2003) confirm the importance of venture capital and point to the effectiveness of particular university policies, namely emphasis on equity investments rather than royalties and minimizing inventor share of royalties so has to preserve the incentives for to create start-ups.

### **d. Universities and Corporate Siting**

By stimulating an innovative environment, universities can play a powerful role in influencing established firms to invest in the local area. Corporate location strategies that focus on the best (technical) learning location in order to tap into networks of innovative activities often highly value geographic co-location with universities. Corporations actively seek to build and maintain competitive advantage through establishing a presence in “learning locations” active in fields of commercial interest (Walcott, 2001).

These firms understand that when a knowledge base is complex, expanding, and widely dispersed, the locus of innovation will be found in networks of learning, rather than in individual firms (Powell, Koput, Smith-Doerr, 1996). In order to tap these university-centered networks, some established firms locate R&D laboratories near the university. Others site significant production facilities and other corporate infrastructure within a university-based cluster. It is also fairly common for large firms to place venture capital or incubator organizations near a university in order to scout out new technologies and talent, and to gain a controlling stake in new ventures of interest to them.

Establishing corporate presence takes a number of different forms. These may include equity investments in local firms, setting up a local R&D facility, or participating in university relationships through industrial partnerships with university departments or through a wide range of collaborative university-industry research centers (Cohen, Florida, and Goe, 1994). While these mechanisms often begin as a way for firms to gain insight into a university department’s research program, they often cement long-term relationships that sometimes lead to a firm’s co-location of facilities.

## IV. The Technology Life Cycle and Strategies for Locally Appropriating the Returns from Investment in Universities

The channels discussed above are not certain to produce lasting benefits to a region. It should be clear that merely planting a research university in the middle of a desert will not lead to knowledge-based economic growth. The strategies that university, policy and business leaders employ, can affect how well a region can appropriate the returns from university RD&E investments.

The strategies that these leaders employ must recognize the stage in the technology life cycle that a technology cluster is currently experiencing.

Early in the formation of an industry, universities are often the primary supporting institutions cultivating would-be high tech entrepreneurs, as they provide R&D infrastructure and research programs that both generate technological opportunities and provide insight into these opportunities. These technological opportunities motivate researchers (both faculty and students) to launch start-ups.

Through this pattern of exploiting local technological opportunities, networks of such firms often emerge closely tied to an academic institution, or some directed public research program that is academic in nature. Often, many of the founders of these firms know each other and are familiar with one another's work. The core technology of the industry at this stage is highly tacit, and difficult for 'outsiders' to pick up. By definition, the industry is restricted to the geographies where the founders are based. And, those geographies that are home to supporting institutions that proactively foster these firms tend to become the center of major technology clusters.

As an industry/technology matures, depending on the nature of the technology, the nature of the knowledge driving innovation in the industry may very well become substantially more codified (less tacit) and more widely sharable. Firms in such an industry may face pressure toward globalization, with price and efficiency meaning more than knowledge advantages. It is at this point in an industry's life cycle that the rich mosaic of supporting institutions that help constitute a geographic cluster are often most important.

To any reader who has made it this far, it is obvious that universities seeking to leverage competitive advantages based on tacit knowledge must ensure that they have the research infrastructure and tal-

ent necessary to compete at the forefront of whatever field they have in their sights. Moreover, universities must pursue R&D in fields that are early in their lifecycle, and thereby amenable to geographic attraction. By cultivating social networks around the bodies of tacit knowledge being generated, universities can deepen the pool of knowledge and create a critical mass that spurs continued benefits. However, if a university applies resources to the recruitment and training, but fails to retain this talent within the region, it could have the exact opposite effect.

At an early stage in a technology's life cycle (not to mention in the life of a technology cluster) universities must encourage start-ups by the faculty and students that are a part in its research capacity in that field. These start-ups help build bridges between the university and the industry. They also contribute back to the region that invested in the research capacity that cultivated them. Start-ups also help weave the fabric of the social networks necessary to retain technical talent, and to provide opportunities and resources to this talent.

Beyond ensuring that start-ups remain local, universities must also ensure that its top talent (more generally) remains in the region, if they are interested in locally appropriating the returns from their investments. Of primary importance is the cultivation of social networks that entice technical and professional graduates to remain local. By leveraging past successes, such as start-ups, and by utilizing alumni networks, universities can play a pivotal role in the formation and growth of such social networks.

These social networks offer individuals a medium through which they can identify opportunities, as well as resources for exploiting these opportunities. However, quality of life variables must also be taken into account. High-end technical and business talent also have lives, and will seek to settle in a location that can support the variety of lifestyles they might be interested in over the course of their lives. As cultural centers and centers of life-long learning, universities are naturally equipped to engage in effective retention strategies if resources are available.

While a university will likely succeed in some initial start-up successes, and in building social networks, there are a variety of additional complementary investments that university, policy and business leaders must make if a vital regional technology cluster is to emerge. Universities can play a significant role at this stage in the technology life cycle, in order to offer the necessary culture of innovation and entrepreneurialism. The construction of research parks, establishment of incubators, luring of venture capital firms, brokering relationships with qualified law firms, and cultivation of business talent are all activities that universities engage in, in order to cultivate regional technology clus-

ters. Concerted effort over time should be aimed at a critical mass of complementary organizations that act independently to promote economic development in the interest of the region. Universities can play a key role in brokering such a situation.

Lastly, universities continue to play a vital role in regional economic development even later in the technology life cycle. Once a research infrastructure is built, social networks are cultivated, talent is produced and retained, and complementary organizations are fostered – there is sufficient raw material for industrial recruitment. Whether this calls for the co-location of industrial R&D facilities, the siting of corporate offices, or the placement of corporate venture (or strategic) capital and scouting operations, industrial recruitment and regional promotion are activities that universities must engage in if they are interested in localizing the economic benefits from their research.

## V. Policy Implications

All of the strategies discussed above are premised upon a university having adequate research infrastructure to pursue a growth strategy. Without sufficient research infrastructure and top-notch talent (e.g., research capacity), no university can serve as the hub for knowledge-based economic growth. And, even if substantial investment is made in research capacity, a university can undercut its own regional economic development strategy if it fails to foster pools of technical talent and the social networks that offer both opportunity and resources.

It is also important to note the limits of university and related initiatives. There are important variables that are outside of a university's control such as general infrastructure, general business climate, and transportation networks. While this paper has focused on the critical role of university RD&E investment (and complementary organizations) in the development of high technology clusters, it is important to recognize that these investments must be taken together with more traditional economic development measures such as infrastructure investments, quality of life initiatives, and the facilitation of face-to-face communication (e.g., air transport, train service, etc.) (Malecki, 1987). Most notably, corporations favor locations (regions) with easy accessibility and professional amenities (Malecki and Bradbury, 1992). Yet, such measures are outside of the purview of the same university administrators that would help guide knowledge-based economic development through university RD&E initiatives.

It is important to recognize that the lion's share of the upside from all of these investments will be enjoyed in the out-years. While the creation of research capacity (through construction and hiring) has immediate impacts that can be measured, it is not the jobs created by the initial phases of university RD&E investments that matter. What matters is the creation of a new source of job creation. By spawning new technical fields and firms that can advance the commercialization of these fields, university RD&E investments serve as the seed corn of knowledge-based economic growth.

In the end, while other public expenditures might be viewed as products or services consumed by the citizenry that have direct economic effects, investments in university RD&E cannot be compared in an apples to apples comparison. Investments in knowledge infrastructure offer transformational opportunities that rework the very nature of a region's economy and its contribution to the global economy. Yet, when making resource allocation decisions, we are faced with a comparison between the immediate and tangible nature of many public investments, and the subtle and complex nature of university RD&E investment strategies, which are perhaps best validated and vindicated by history.

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