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BIOTECHNOLOGY CENTERS AND TECHNOLOGY–BASED ECONOMIC DEVELOPMENT

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Abstract

The purpose of this paper is to foster a broad and general understanding of the relationship between the establishment of biotechnology centers and economic development at the state level, and to consider whether a state biotechnology center is a critical infrastructural element of a state's overall economic development strategy. The evidence is not conclusive that a state biotechnology center is the most efficient way for a state to stimulate its biotechnology industry.

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Biotechnology Centers and Technology-Based Economic Development

I. INTRODUCTION

The purpose of this paper is to foster a broad and general understanding of the relationship between the establishment of a biotechnology center and economic development at the state level, and to consider whether a state biotechnology center is a critical infrastructural element of a state's overall economic development strategy.[1]

The paper is outlined as follows. Section II briefly sets forth an abbreviated framework for technology-based economic development at the state level, and the potential role of a state-based biotechnology center is highlighted within that framework.

In Section III, the history of biotechnology clusters is briefly reviewed because cluster formation is a market response to development in the biosciences while, in contrast, the formation of state-based biotechnology centers is one of several non-market responses proffered by a state to overcome presumed barriers to the development of an intra-state biotechnology industry.

Section IV presents summary data on the existence of state biotechnology centers, along with other information about which infrastructures states are using to encourage the development of a biotechnology industry.

Section V discusses the role of state biotechnology centers in light of economic arguments for the public sector's (i.e., the state's) role in innovation.

Section VI offers observations about the efficiency of biotechnology technology centers to leverage the development and growth of an intra-state biotechnology industry and thus stimulate economic development. Also, bioscience and economic development efforts in Kansas are highlighted.

Finally, the paper concludes in Section VII with possible lessons to be learned about biotechnology centers relative to other state actions related to technology development.

II. A MODEL OF TECHNOLOGY-BASED ECONOMIC DEVELOPMENT

A model of technology-based economic development (TBED), at the state level, begins with a descriptive relationship among technology-related inputs and outputs, and development-related outcomes:

Inputs → *Outputs* → *Outcomes*

Generally, the inputs in a TBED model are inventions, and the outputs are innovations.[2] Outcomes include new technology-based companies or expanded existing technology-based companies (these are often referred to as first-order outcomes) and the multiplier-related economic development associated with company growth (and these are often referred to as second-order outcomes).

Thus, an expanded representation of a TBED model is represented as:

Inventions → *Innovations*
→ *Technology-based Companies*
→ *Broader Economic Development*

Technology-based economic development (TBED) is a phrase that state planners and forward-looking university leaders have been using over the past several years as a strategy to respond to the overall national slowdown in economic activity. However, this phrase is misleading; in most cases it neither describes what states are doing nor does it characterize accurately what they plan to do. It is true that at the aggregate level technological change is positively correlated with economic growth, but what that correlation likely reflects is an underlying relationship between inputs into the innovation process – research and development (R&D) activity in particular – and economic growth. And, what leverages the R&D-to-growth relationship are infrastructures that bring about efficiencies in the R&D process. What the Nation has done through innovation and technology policies in the post-World War II period is foster a technology-based infrastructure, and this is precisely what states are now doing. For exactness, then, the acronym TBED should possibly be replaced with *I*BED – *infrastructure*-based economic development.[3]

Critical to understanding how such a TBED model works in practice is an awareness of the infrastructural elements that leverage each of the stages of the model. In particular, and the following discussion is relevant to biotechnology-based economic development:

- R&D infrastructure leverages the transformation between inventions and innovations. Elements of an R&D infrastructure include a state's available science and technology researchers, its science and technology facilities and equipment, its university-based resources, and, possibly, its biotechnology center.
- The transformation between innovations and technology-based companies is leveraged by a state's commercialization infrastructure. Elements of a commercialization infrastructure include a state's university-based science/research parks and institutes, a biotechnology center, as well as the availability of other sources of commercialization funding, incubators, and an overall entrepreneurial climate.

Finally,

- The transformation between companies and broader economic development is leveraged by an educational workforce infrastructure. Elements of an educational workforce infrastructure include aspects of a science and technology related focus in community colleges and universities.

It is these infrastructural elements, rather than the technology itself, that leverage economic development.

III. GROWTH OF BIOTECHNOLOGY CLUSTERS

Defining bioscience as the search for new knowledge in the biological sciences, and biotechnology as the application of bioscience to new products and processes, the biotechnology industry began with several key breakthroughs in the biosciences.[4]

- In 1953, Watson and Crick discovered the double helix structure of DNA.
- In 1957, Kornberg revealed how DNA is replicated through the discovery of the enzyme DNA polymerase I.
- In 1973, Cohen and Boyer developed the recombinant DNA (r-DNA) technique.
- In 1975, the first monoclonal antibodies were discovered.

Each of these breakthroughs resulted in large part from publicly-funded university-performed research, hence the observation (see inserts) that biotechnology clusters historically grew around university research and researchers.

Market responses followed these breakthroughs. Dedicated biotechnology firms (DBFs) located around the "star scientists" in this burgeoning field, and then, in response, biotechnology commercializing firms (BCFs) located around the DBFs. As a result, biotechnology clusters began to form and grow.

Today, there are nine metropolitan areas within the United States that are homes to 75 percent of the Nation's largest biotechnology firms.[5] The origins of biotechnology clusters trace to the San Francisco (see insert) and Boston/Cambridge areas (see insert). The other cluster areas are, in order of when they developed, Philadelphia, New York, San Diego, Seattle, Raleigh/Durham, Washington/Baltimore, and Los Angeles.

IV. STATES WITH BIOTECHNOLOGY CENTERS

There is not a generally accepted definition of a biotechnology center.[6] Thus, any taxonomy of biotechnology centers has a subjective element. For the purpose of this paper:

> A state biotechnology center is defined herein to be an state-related infrastructural organization created using state funds, in total or in part, for the purpose of stimulating public and private sector research in biotechnology within the state.

And, the goals of a state biotechnology center include both general education about biotechnology and the means to foster economic development through sponsored research.

Given this definition, few states have state biotechnology centers. All states promote an educated workforce to support their biotechnology industry, as well as other internal industries.[7] And, all states have a Department of Commerce (by that name or by a similar name) with, among other things, a mission to retain existing and attract new organizations, including bioscience and biotechnology companies, into the state. Many states also have a separate state association or council with a specifically stated mission to grow and improve the economic environment of the state's biotechnology industry. And finally, a few states have the architecture of a state biotechnology center, as defined above.[8]

Table 1 lists all states in descending order of the amount of total university R&D in the state in 2002 (the latest data available). The reason for this representation comes from the fact that university R&D is a complement to the research activities in both bioscience and biotechnology firms. The table also summarizes different aspects of the technology infrastructure of states.

Table 1 reports those states that have a specific biotechnology association or council that is separate and apart in organizational form but not necessarily in purpose, from the state's Department of Commerce.[9] To the extent that the information in Table 1 is complete – and it could well be the case that a state has a specific biotechnology association or council but that the organization's activities are not broadly known – it appears that advocacy for building a biotechnology industry within a state is positively related to its science base within the state, as proxied by the level of university R&D within the state. That is, it appears to be the case that there are more state biotechnology associations and councils in states with greater university R&D than in states with lesser university R&D.

Five states are highlighted in Table 1 using bold print. These are Maryland, Massachusetts, North Carolina, Georgia, and Connecticut. Each of these states is among the more university R&D intensive states. Each of these

The North Carolina Biotechnology Center

In 1981, the North Carolina Biotechnology Center (NCBC) was created by the North Carolina General Assembly. It was the Nation's first state-sponsored initiative to develop biotechnology, and as such this initiative gave "political verification" to the idea that the state could stimulate the birth of this industry. The Center was originally housed in the North Carolina Board of Science and Technology in Raleigh as part of state government, but to give it more flexibility and non-partisan neutrality it was reconstituted as a non-profit corporation on August 17, 1984, with an annual budget of $6.5 million.

The Center's mission is to provide long term economic benefit to North Carolina through support of biotechnology research, development and commercialization statewide. And toward this mission, the Center's 40-member staff works in pursuit of five goals, and these five goals involve industry, universities, and the state in one way or another:

- Strengthen North Carolina's research capabilities in its academic and industrial institutions
- Foster North Carolina's industrial development
- Inform and educate the public about biotechnology
- Develop mutually beneficial partnerships among all parties involved in moving biotechnology from research to commercialization
- Establish for North Carolina a leadership role in biotechnology and its commercialization

The North Carolina Biotechnology Center's location within the universities' home acreage in Research Triangle Park is symbolic of the interplay between industry and academe that is necessary for the state to grow a biotechnology industry.

The Center has been very successful in fulfilling its mission and goals. North Carolina companies five states has the architecture of a state biotechnology center as defined above (and given the caveat that public information sources are not complete).[10]

The Nation's first state-sponsored economic development initiative to develop biotechnology was in North Carolina through the North Carolina Biotechnology Center (see insert).[11] This is the most developed center among the five highlighted in Table 1. The other four centers provide critical state infrastructural support for the development of their bioscience and a biotechnology industry.

BioAlliance in Maryland is an organization with the mission of building the state's investments in biotechnology by fostering a network of companies, research organizations, academia, and government laboratories.

The Massachusetts Biotechnology Council began as an association in 1985 but today has more of the characteristics of a center than an association or council. Its mission is to foster a positive environment to enable bioscience and biotechnology companies to efficiently be a part of the building of a world cluster for biotechnology. It provides not only infrastructure but also it advocates for the biotechnology industry in legislative and educational matters.

The Georgia Biomedical Partnership is organizationally similar to the Massachusetts Council in that its mission is to build Georgia's life science community and provide, for its members, networking opportunities.

The Connecticut Bioscience Cluster is a non-profit corporation with the mission to increase bioscience companies in the state of Connecticut. It is active in developing the state's workforce as well as in championing state and national policies favorable to its bioscience industry.

Biotechnology associations, councils, and centers are not the only infrastructural elements in place in states. As shown in Table 1, many states have university-based biotechnology research centers within their educational sector; and, as shown in Table 1, some, yet slightly fewer, states have also established university-related science/research parks with some degree of bioscience or biotechnology emphasis.

A comparison of the information in Tables 1 – although the table does not contain information on the year in which any of the three sets of infrastructural biotechnology initiatives were begun and although no specific economic outputs from any of the three biotechnology initiatives are available – shows that it is the case that biotechnology centers are the least frequently used

are responsible for about 10 percent of the Nation's $12 billion biotechnology industry. In 1984 there were 6 North Carolina companies in biotechnology; in 1988 there were 15 to 20 with about $100 million in sales; in 1998 there were 80 companies with $1.2 billion in sales; and in 2005 there were nearly 175 companies with sales over $4 billion.

The Origins of the San Francisco Biotechnology Cluster

In 1976, Genentech (a DBF) was founded in San Francisco by venture capitalist Robert Swanson of Kleiner Perkins and professor Herbert Boyer of the University of California at San Francisco. The goal of the new company was to use bioscience to synthesize human insulin. This was accomplished in 1978. In 1979, Genentech developed the first synthetic human growth hormone, somatropin. In 1982, the Food and Drug Administration (FDA) approved the Genentech – Eli Lilly (a pharmaceutical company and a BCF, as well as a competitor of Schering-Plough) product, Humulin, for commercial use.

The Origins of the Boston/Cambridge Biotechnology Cluster

In 1978, Biogen (a DBF) was founded in Cambridge, MA, by Harvard professor Walter Gilbert, among others, including MIT professor Phillip Sharpe. In 1980, based on the Nobel Prize winning research of Gilbert in sequencing nucleotides, Biogen agreed to allow pharmaceutical company Schering-Plough (a BCF) to license beta interferon.

Table 1

States Ranked by University R&D ($1,000) and University R&D Per Capita in 2002

	Total	Per Capita	Per Capita Rank	State Bio-technology Council or Association	University-based Bio-technology Research Center	University-based Bioscience focused Research Park
California	$4,881,803	$139.02	18	X	X	X
New York	$2,761,376	$144.14	16	X	X	X
Texas	$2,535,237	$116.40	25		X	X
Pennsylvania	$1,912,760	$155.07	10	X	X	X
Maryland	$1,880,122	$344.47	1	X	X	X
Massachusetts	$1,697,102	$264.03	2	X	X	X
Illinois	$1,440,538	$114.32	26	X	X	
North Carolina	$1,276,655	$153.45	12	X	X	X
Michigan	$1,233,076	$122.69	24	X	X	X
Ohio	$1,116,957	$97.80	35	X	X	X
Florida	$1,085,764	$64.96	45	X	X	X
Georgia	$1,076,424	$125.74	22	X	X	
Wisconsin	$805,813	$148.10	14	X		X
Washington	$782,886	$129.00	21	X	X	X
Missouri	$705,593	$124.39	23	X	X	
Virginia	$693,606	$95.09	38	X	X	X
New Jersey	$690,642	$80.40	43	X	X	X
Indiana	$650,718	$105.66	32	X	X	X
Colorado	$645,291	$143.19	17	X		X
Connecticut	$538,070	$155.49	8	X		X
Arizona	$531,106	$97.33	37	X	X	X
Minnesota	$504,257	$100.46	33	X	X	
Alabama	$503,470	$112.22	27	X	X	X
Tennessee	$490,994	$84.70	39	X	X	
Iowa	$485,756	$165.41	6	X	X	X
Louisiana	$482,404	$107.62	31		X	X
South Carolina	$399,982	$97.39	36	X		
Oregon	$386,666	$109.80	29	X	X	X
Utah	$359,556	$155.23	9	X		X
Kentucky	$332,853	$81.33	41		X	X
Kansas	$299,728	$111.37	28		X	
New Mexico	$292,691	$157.79	7		X	X
Mississippi	$285,466	$99.41	34			
Oklahoma	$282,062	$80.74	42		X	X
Nebraska	$266,930	$154.38	11			
New Hampshire	$220,061	$172.59	4	X		
Hawaii	$172,664	$138.70	19	X		
Rhode Island	$163,052	$152.42	13			
Arkansas	$140,283	$51.77	49	X	X	
Alaska	$128,875	$200.17	3			
Nevada	$126,713	$58.29	46			
Montana	$122,375	$134.56	20		X	
North Dakota	$106,078	$167.28	5			
West Virginia	$96,870	$53.76	47		X	X
Idaho	$93,323	$69.59	44			X
Vermont	$90,189	$146.27	15			
Delaware	$88,319	$109.40	30		X	X
Maine	$69,222	$53.48	48	X	X	X
Wyoming	$41,632	$83.48	40		X	
South Dakota	$38,449	$50.51	50			

Source: Battelle Memorial Institute (2004) and public-domain Internet information. Link and Scott (2006).
Note: States are listed in descending order of the amount of total university R&D in the state. States in bold are among the more university R&D intensive states. Each of these states has the architecture of a state biotechnology center as defined on page 2.

infrastructural elements associated with biotechnology-based economic development. Many more states have university-based biotechnology research centers and university-based science/research parks with a bioscience focus than have state biotechnology centers.

What is also clear from the table is that states with biotechnology centers, albeit that they are in the more university R&D intensive states, are not in every instance associated with university-based biotechnology research centers, or with university-based science/research park initiatives aimed toward biotechnology.

V. THE PUBLIC SECTOR'S ROLE IN INNOVATION

The federal government has long had a partnership role with the private sector in fostering innovation. The sequential logic of this partnership role rests on the following four premises. The first two premises are:

- Innovation leads to technology.
- Technology is the primary driver of economic growth.

The motivation for the first two premises can be traced indirectly to Vannevar Bush's 1945 report, *Science-the Endless Frontier*. In his transmittal letter to President Roosevelt dated July 25, 1945, he stated:

> The reward of [innovation] … for the Nation [is] great. Scientific progress is one essential key to our security as a nation, to our better health, to more jobs, to a higher standard of living, and to our cultural progress.

In the report, Bush wrote (1945, p. 15):

> A nation which depends upon others for its new basic scientific knowledge will be slow in its industrial progress and weak in its competitive position in world trade.

More directly, the Nation's first formal technology policy, *U.S. Technology Policy*, stated that innovations lead to new technology and (1990, p. 2):

> The goal of U.S. technology policy is to make the best use of technology in achieving the national goals of improved quality of life for all Americans, continued economic growth, and national security.

The third premise is:

> In the absence of governmental intervention, firms will underinvest in the innovation process, especially in R&D.

The economic underpinnings for this third premise, in particular, or, in general, for the public sector – federal or state government – to be involved in the innovation process rests on the economics concept of market failure. Conditions can exist under which the market – the R&D investing producers of a technology and the users of the technology – underinvests, from society's standpoint, in a particular technology. Such underinvestment occurs because conditions exist that prevent organizations from fully realizing or appropriating the benefits created by their investments.

The fourth premise is simply a summary statement based on the first three premises.

> Government has a responsibility to address this underinvestment by providing incentives for the continued conduct of, or perhaps increase in, R&D.

Focusing on biotechnology from a state's perspective, there are a number of barriers or factors that explain why companies will invest less in biotechnology – meaning allocate fewer resources toward starting a dedicated biotechnology firm (DBF) or a biotechnology commercializing firm (BCF) – than the state deems socially desirable. These barriers include:

> **Technical Risk.** A company may perceive that the results from the biotechnology research or development may not be technically sufficient to make the venture profitable. Hence, a company's perception of the private return from its investments will fall short of the social return.

> **Market Risk.** Even if the underlying research is technically successful, the developed biotechnology may not be commercially successful in the market. The company's private return will fall short of the social return.

Evolving Nature of Markets. Because of the evolving nature of technology-based markets, a company may need investments in a combination of biotechnologies that could reside in different industry segments that may not be integrated, and a company may have insufficient financial capital to pursue an economies of scale strategy across industry segments.

The role of the public sector is to reduce company barriers that bring about market failure, that is, to reduce the barriers associated with the private return from investments in biotechnology being less than the return needed for a firm to enter the market. Specifically, the public sector should reduce technical risk, reduce market risk, and provide opportunities for collaborations to counteract needed economies of scale across industry segments.

VI. THE EFFICACY OF BIOTECHNOLOGY CENTERS

Is a biotechnology center the most efficient way for a state to stimulate and support the development and growth of a biotechnology industry? Based on a comparison of the information in Table 1, most states apparently do not think so. Most states, based only on the relative number of states that have pursued alternative technology-based economic development strategies, have alternatively invested in university-based biotechnology centers or university-based science/research parks with a bioscience focus as opposed to formal centers. Of course, biotechnology centers, as defined herein, and university research endeavors are not substitutable activities, but they do compete for a finite amount of state resources.

Stating the above question differently: Is the creation of a state biotechnology center, as defined above, the most efficient way to reduce the barriers associated with the private return from investments in biotechnology being less than the return needed for a firm to enter the market? One possible interpretation of the information in Table 1 could be that states view university-based biotechnology research centers as an effective infrastructure to lessen technical risk barriers associated with bioscience research and the transition from bioscience to biotechnology. A second possible interpretation could be that states view university-based science/research parks as an effective infrastructure to lessen market risk barriers and to provide the opportunity to achieve the needed economies of scale across industry segments.

In fact, there are a number of other activities that states pursue that could more efficiently reduce the barriers that bring about market failure, and these activities are logically less expensive and more focused than the creation of a state biotechnology center. These activities include, but are not limited to:

- Provision of investment capital to lessen market risk.
- Development of a more highly trained workforce to lessen technical risk.
- Formation of university-based incubators to lessen technical risk.

If the observed activities of states are an indicator of best practices, then it appears from the information in Table 1, and based on the economic rationale for public sector involvement in innovation, that the intellectual foundation of universities is an important key to the development and growth of a state's biotechnology industry.

As seen from Table 1, Kansas ranked in 2002 31st in terms of total university R&D, and it ranked 28th in terms of university R&D per capita. Although neither its absolute or relative ranking is impressive, the fact that Kansas ranked 2nd in the Nation in terms of absolute growth in university life sciences R&D between 1996 and 2002 – a 74.1 percent increase compared to the national increase of $68.8 percent[12] – is extremely encouraging given that R&D directed toward the life sciences is one necessary condition for future prominence in biotechnology. Complementarily, the Kansas Bioscience Authority and the Kansas Technology Enterprise Corporation have strategically devoted resources to formulate the Regional Bioscience & Innovation Roadmap and to promote economic development in the biosciences. While these initiatives are distinct from the established biotechnology centers, they, especially the roadmap effort, have the potential to have a greater impact on developing a synergy between university life sciences R&D and economic growth in the sciences.

To the extent that a lesson can be drawn from one experience, the development of SEMATECH and the semiconductor industry roadmap not only fostered growth in that technology but also helped the industry anticipate burgeoning technologies. One such burgeoning technology that will affect advances in the biosciences as well as advances in many other fields is nanotechnology, as discussed below.

VII. CONCLUSIONS

One could make the argument that states are viewing nanotechnology, as a potential driver of economic development, today as they did biotechnology two decades ago. And today, related to nanotechnology, there is not sufficient evidence that states are turning to centers, in concept like biotechnology centers, to stimulate economic development.

Nanotechnology, based on the definition set forth in the National Nanotechnology Initiative,[13] refers to the science and engineering fields that work at the nanoscale level.[14] As with any technology, burgeoning or not, there exists technical and market risks that cause an underinvestment from society's perspective.

At the present time, approximately 20 states have or are in the process of preparing nanotechnology initiatives. The purpose of these state-based initiatives is to address the infrastructural needs of the state so as to provide an environment most conducive for the development of industries that rely on nanotechnology. These initiatives are not dissimilar from the historical goals of states in the area of biotechnology.

None of the state nanotechnology initiatives advocates the establishment of a state nanotechnology center to coordinate activities to foster the growth of the industry. Rather, all of the state initiatives advocate, to some degree or another, the role of university-based research centers and enhanced educational programs as infrastructures to reduce technical risk.[15]

ENDNOTES

1 This statement and those that follow assume that any existing or planned biotechnology center would operate efficiently.

2 Invention is the creation of something new. An invention becomes an innovation when it is put into use.

3 In my opinion it is unlikely that the phrase infrastructure-based economic development will "catch on" because it is very difficult to replace a phrase that has wide spread usage and because technology is a concept more easily understood than infrastructure.

4 This historical timeline comes from http://www.ncbiotech.org/biotech101/timeline.cfm and from Orsenigo (1989). Teitelman (1989) also provides an excellent documentation of the evolution of the biotechnology industry.

5 See Cortright and Mayer (2002).

6 This definition does not include biotechnology research centers at state universities, as discussed below.

7 See www.bio-link.org.

8 Because state biotechnology centers, as organizations, are growing and evolving, some, like the one in North Carolina, are more mature than others. Thus, emphasis is given to states with the architecture of a center.

9 The information in Table 1 comes from Battelle Memorial Institute (2004) and public-domain Internet information.

10 Based on extant information it is a subjective judgment, with the exception of the North Carolina Biotechnology Center, to separate the so-labeled centers in Maryland, Massachusetts, Georgia, and Connecticut from the other states with biotechnology associations.

11 Quoted from www.ncbiotech.org

12 See Battelle Memorial Institute (2004).

13 See http://www.nano.gov/html/about/home_about.html.

14 A nanometer is one one-billionth of a meter.

15 Market risk is less of a barrier that leads to market failure in nanotechnology than in biotechnology because nanotechnology is an integrative technology that is used by companies in existing markets.

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