The Locational Dynamics of the U.S. Biotech Industry:

Knowledge externalities and the Anchor Hypothesis

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August 15, 2002

Abstract : Biotechnology, rather than defined as a distinct industry like automobiles or steel, is instead a scientific knowledge base -- a rapidly evolving technology -- that has economically valuable applications in such diverse industries as pharmaceuticals, medical diagnostics, agriculture, bio-environmental remediation and chemical processing. Biotechnology has captured the imagination of ambitious scientific investigators, investors seeking high rates of return, as well as economic development officials who hope to anchor the industry within their district and reap the economic and employment rewards. Biotech is still at an early stage and there are many competing hypotheses about its future development. This paper adapts the concept of the anchor tenant from real estate economics to explore the locational concentration and specialization of the emerging biotech industry. Established Anchor firms who use a new technology may create knowledge externalities that benefit smaller dedicated biotech firms and increase overall innovative output in the region. In the situation of a shopping mall, the market failure is addressed through rents. In the absence of such a transfer mechanism among firms, we may except that smaller firms would benefit from a location premium and this would result in a greater number of new start-ups and better performance.

Keywords: Knowledge spillovers, agglomeration economies, and biotechnology

Prepared for the Danish Research Unit on Industrial Dynamics (DRIUD) 2002 meetings. Thanks to Morris Teubal, Mark Lorenzen and the audience for comments. This paper has benefited from discussions with David Audretsch, Iain Cockburn, Johanna Francis and Elaine Romanelli. Invaluable research assistance in the preparation of the database was provided by Ivar Strand, Nathan Dienes, Tom West and Johanna Francis. This work is part of a larger ongoing project. Comments and suggestions are appreciated. These results are preliminary. Please check with the author before citing for additional work,

Introduction

One of the important motivations in economic geography is to understand the forces that contribute to the agglomeration of innovative activity and affect the growth potential of the firms and cities. A significant body of research examines this question and demonstrates the importance of knowledge spillovers (see Feldman 1999 for a recent review). More recent work highlights the importance of industry life cycle (Duranton and Puga 2001), the composition of activities within an agglomeration (Glaeser et al. 1992; Henderson et al. 1995, Feldman and Audretsch 1999) and the effect of existing industrial structure (Klepper 2001; Rosenthal and Strange forthcoming). This work suggests a more nuanced understanding of the nature of agglomeration economies and the way in which the fortunes of firms and regions are intertwined.

Biotechnology, the commercialization of scientific discoveries related to genetic engineering, provides an example of a new industry formed primarily by entrepreneurial start-ups. The industry has captured the imagination of ambitious scientific investigators, investors seeking high rates of return, as well as government officials who hope to capture the industry's potential economic and employment rewards. Biotech, however, is still at an early stage and there are many competing hypotheses about the nature and direction of its future development. Biotechnology presents an opportunity to study the emergence and development of a new industry that has a strong science base coupled with great commercial potential. While significant resources are spent trying to promote new firm formation and the development of biotech clusters, we have a limited understanding of the process by which new industries become anchored in a local economy and, as a result, how locations may reap the resulting economic rewards.

This paper uses a panel of firms to explore the locational patterns and place-specific evolution of the in the U.S. biotech industry. As predicted from prior studies of knowledge-intensive industries, the biotech industry is becoming more geographically concentrated and highly specialized in certain locations. While the existence of knowledge externalities contributes to geographic concentration the larger question of how regional specialization is determined and how this affects firm survival and growth and subsequently the viability of the regional cluster is relatively unexplored.

One answer may be that existing firms may serve as anchors that establish skilled labor pools, specialized intermediate industries and provide knowledge spillovers for new technology intensive firms in the region. Established firms may provide expertise and knowledge about specific applications, product markets, and technical developmental trajectories that move generic scientific innovations in a particular direction, which, over time, may distinguish the specialization of the industrial cluster. For example, if there is a regional anchor with a sophisticated expertise in vaccines, new start-up firms may be likely to specialize in that trajectory. Once the region is noted to have developed an expertise, others that work on the application or in the product market may be encouraged to start firms in the region. Over time, a cluster develops around a specialized expertise. This implies a regional path dependency that stems from the existence of the anchor firm to the specialization of new firms that enter the industry in that location. As a result, the fortunes of technologies, firms, and regions are jointly determined.

The next section of the paper examines the historical development of the biotech industry. The next section develops the concept of a regional anchor. Section 3 sets out some of the empirical patterns of geographic location and specialization in the biotech industry. Section 4 develops the concept of the Anchor firm as an agglomerative force and provides hypotheses about the Anchors' relationship to the formation of new dedicated biotechnology firms and their growth. Section 5 provides empirical tests of these hypotheses. Section 6 concludes with some reflective conclusions and future areas of research.

Biotechnology as an emerging industry in a regional context

The biotechnology industry is a collection of firms that focus on the application of recombinant DNA (rDNA) and its related technologies. This industry is based on a series of scientific advances in the twentieth century that provided key insights into the biological basis of life (Kenney 1986:9-27).[1] This technology may be conceptualized as a radical scientific breakthrough that creates a platform for revolutionary economic growth (Rifkin 1999). Just as our understanding of chemistry in the prior century revolutionized products and production processes in such diverse industries as the dye industry, pharmaceuticals, agriculture and fuel, biotechnology displaces the focus from chemistry to molecular biology in applications across a variety of industries.

The birth of the biotechnology industry may be dated to 1973 with a series of patent applications that were filed by Professors Stan Cohen of Stanford University and Herb Boyer of the University of California at San Francisco.[2] The patents provided a technique for moving genes between organisms and transformed the basic science of molecular biology into commercially useful knowledge. The timing of these discoveries coincided with a new era of active technology transfer by American research universities that relied on patenting scientific discoveries and then licensing the right to use these patents to firms to increase the commercialization of academic research.[3] Many new dedicated biotechnology firms (DBFs) have been formed around licenses of university patents (Powell and Brantley 1992) and maintain strong ties with academic researchers (Zucker and Darby 1996; Audretsch and Stephan 1996).

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[1] Modern biotechnology traces its origins to the discovery of the molecular structure of the basic building block of genetic material, deoxyribonucleic acid or DNA, by James Watson and Francis Crick in the 1950s. This work made it possible to identify the genes that make specific proteins. James Watson and Francis Crick were awarded the Nobel Prize in Medicine in 1962 for this work. See Watson (1981) for an account of the discovery process.
[2] Hall et al. (2001) argue that the patent application date should be used to date inventive activity as the lag between application and grant dates reflects administrative policies at the U.S. Patent Office.
[3] For example, in licensing the Cohen-Boyer patents on recombinant DNA technology, Stanford University asked for a one-time licensing fee of $10,000 and royalty rates ranging from 0.5% on sales of end products such as insulin to 10% on sales of research vectors and enzymes (Scherer 1999: 55).

From its embryonic beginnings the biotech industry is now about thirty years old. As a new industry, biotechnology is not part of the standard industrial classification system that economists usually use to study an industry.[4] As a result, studies have used a variety of proprietary data to study biotechnology. Unfortunately, most biotech firms are small and publicly held. Biotech firms are noted to have faced greater difficulties at initial public offering (IPO) due to the embryonic stage of development of their technology and the potential for long regulatory delays in bio-medical applications and public skepticism in agricultural and environmental applications.

This paper examines data from BioAbility (formerly known as the Institute for Biotechnology Information), which maintains a proprietary database of U.S. biotechnology companies. The database provides company profiles on more than 1,700 biotechnology and biotechnology-related corporations in the United States, including company location, year of founding, product areas, technology used, number of employees, annual revenues, and type of financing and corporate associations. The data are updated frequently using various sources including, but not limited to, company press releases, company web pages, numerous periodicals and journals, SEC reports, annual reports, and direct contact with company officials.[5] These data are described as a "complete information source on biotechnology in the United States" and is primarily sold to companies who are interested in marketing and competitive intelligence.[6] These data have been used extensively by other researchers (Greis *et al.* 1995; Prevenzer 1997; Zucker and Darby, and their colleagues, Swann and Baptista; Feldman and Ronzio 2001; Hall 2001) and

[4] Toole (forthcoming) relies on SIC code 283: and SIC code 8731 to capture the human therapeutics and diagnostics segments of the biotechnology industry. However, it is not a clean measure because SIC 283 includes traditional pharmaceutical firms and SIC 8731 includes commercial physical research companies.
[5] See the BioAbility company webpage for more information (http://www.bioability.com/Database.htm).
[6] To check these data, Feldman and Ronzio (2001) cross-referenced companies in Maryland identified by BioAbility with companies identified by other sources. The BioAbility data missed a total of 55 companies that were identified by the CorpTech Directory and Maryland Technology Resource Council. However, IBI identified 20 companies that the other two references missed. There does not appear to be any discernable bias in the companies that are included by the various sources but only serves to note the difficulty in defining an emerging industry.

offer a snapshot of the industry at a specific point in time. The BioAbility data will be used here to examine the locational patterns of the industry.[7]

Regional Distribution of the Industry

Knowledge-intensive, early stage industries are expected to be geographically concentrated. Prevezer (1997) reports that there were 849 dedicated firms in the biotech industry in 1991, with sixty-three percent (536 firms) located in eight (out of a total of fifty) states. In 1997, there were 1,478 dedicated biotechnology firms and 1,497 firms in 2001.[8] It should be noted that 47 of the 50 states had at least one biotech firm (the exceptions were South Dakota, Wyoming and Alaska), perhaps reflecting incentives targeted to encourage the development of the biotechnology industry within their borders (Biotechnology Industry Organization 2001).[9]

[Table 1]

Table 1 demonstrates that while the concentration of dedicated biotech firms in the top states increased slightly from 1991 to 2001, the relative ordering of states changed with New Jersey losing ranking while Maryland and North Carolina moved forward with a greater number of firms. What is most surprising is that the top three states (California, Massachusetts and New Jersey) accounted for 38 percent of the industry in 1991, 40 percent in 1997 and 42 percent in 2001 (California, Massachusetts and North Carolina). Thus, there is somewhat of a paradox. The

[7] The data presented here have been checked for accuracy and cleaned (see Appendix).

[8] There are two distinct types of firms in the biotech industry and in the BioAbility data. Dedicated biotech firms (DBFs) are young firms that have biotechnology as their focus. The biotech industry began in the early 1970s and the analysis excludes firms that were founded prior to 1970. In addition, there are many larger and more established entities that have only a small interest in biotech are not considered as dedicated biotech firms.

[9] Forty-eight out of fifty states have programs aimed at spurring development of the life sciences, according to the 2001 Biotechnology Industry Organization study. For example, Wisconsin has directed that about $65 million of its public employee pension funds be invested in young life-sciences companies. Michigan is spending $50 million a year for 20 years, or $1 billion, from the state's share of the tobacco settlement to nurture a life sciences corridor from Detroit to Grand Rapids. Kentucky has been trying to lure academic stars to the universities by supplementing their salaries with its "Bucks for Brains" program. New York State this year allocated $225 million for the Gen*NY*sis program to support biotech research which supports business incubators to house fledgling companies and compensate for the expensive real estate near New York City leading medical research centers.

industry is simultaneously becoming more distributed to a variety of locations. This may be due to state initiatives to promote the industry. At the same time, the industry is becoming more geographically concentrated in a few locations. Moreover, the relative ranking of these locations is not static.

[Table 2 about here]

Table 2 provides the sub-state distribution of the industry in 1997 and 2001 for those cities that had the largest concentrations of firms.[10] The largest number of dedicated biotech firms were located in the Boston area (142 firms or 10 percent of the industry), followed second by San Diego (107 firms or 7 percent of the industry) and San Francisco (76 firms or 5 percent of the industry). In sum, these seventeen cities account for 60 percent of the biotech firms. The top four cities accounted for about 28 percent of the firms. Only about 4 percent of the firms were not located in an urban area in 1997 or in 2001, consistent with other analysis of innovative activity that finds that innovation is an urban phenomenon (Feldman and Audretsch 1999).

The rank-order of cities in terms of the distribution of firms is not static over this four year time period. The Boston and San Francisco areas, where the industry is noted to have had its origins in the 1970s are among the leaders (Cortright and Mayer 2002). The industry in Boston is substantially concentrated in Cambridge while the Northern California industry is spread between San Francisco's neighboring jurisdictions of Oakland and San Jose. San Diego, Seattle and Raleigh-Durham are typically seen as concentrations that emerged later but have developed substantial industries. Raleigh-Durham, the city associated with Research Triangle Park, had the greatest increase in the number of firms and moved from fifth to third in the rankings between 1997 and 2001. The Washington, D.C. cluster is frequently cited as benefiting from proximity to the U.S. National Institutes of Health which accounts for $25 billion in intramural research funding. Conversely, New York and Philadelphia are two cities that are historically prominent

[10] Geographic assignment, based on the address of the firm uses Primary Metropolitan Statistical Area (PMSA).

headquarters for the pharmaceutical industry. In contrast, Los Angeles and Orange County in Southern California is noted to be the home of Amgen, one of the earliest and currently the world's largest biotech company.[11] Thus, the geographic location of the industry appears to be anchored by some large institutions, related firms and successful early entrants to the industry.

Technological Specialization

Biotechnology is a scientific knowledge base that has economically valuable applications in such diverse industries as pharmaceuticals, medical diagnostics, agriculture, bio-environmental remediation and chemical processing. There is evidence of regional specialization in biotech products and technological sub-fields that suggest there are unique and regionally defined centers of expertise.

[Table 3 about here]

We analyzed the regional concentration of product categories by city for the cities with the largest number of dedicated biotech firms in Table 3. For example, Boston, Massachusetts was the site for 142 firms in 1997. Of these 142 firms, 67 firms had an active interest in therapeutics. This represents 42.41 percent of the firms within the city. The location quotient measures the degree of specialization of the firms within a city relative to the nation.[12] A location quotient of 100 indicates that the city has the same proportion of companies specialising in a certain product category as the national industry. In Boston, the location quotient for therapeutics is 155, indicating that the industry concentration in therapeutics is 55 percent greater than if firms

[11] Amgen's website (http://www.amgen.com/corporate/AboutAmgen/backgrounder.html) indicates that the company chose Thousand Oaks, California as its location to be near such major research centers as the University of California at Los Angeles, the University of California at Santa Barbara and the California Institute of Technology.

[12] It is calculated as the ratio of the percentage of the state's biotech firm with a specific specialization divided by the percentage of the nation's biotech firms with that specialization.

specializing in therapeutics were evenly distributed throughout the country. These results suggest that the industry is developing differentiated and unique capabilities in specific locations.[13]

[Table 4 about here]

In contrast, Table 4 presents location quotients for cities that do not have a prominent presence for the industry overall but exhibit a high degree of specialization. It is most surprising that the cities listed are not typically considered as hot beds for technology and lack many of the prerequisites for science-based industry development, notably prominent research universities. For example, Des Moines, Iowa does not have a major university. It does have a set of large established firms with a reputation for R&D in animal products such as Garst Seed Company (established in 1930; 450 employees); Hy-Line International (established in 1936; 300 employees) and Pioneer Hi-bred International (established 1926; 5,025 employees). These firms are part of the BioAbility database because they have activity in biotechnology.[14]

While the term biotechnology is used to describe an entire industry, it is really a set of many different product applications in the categories noted above. Following the path of most generic platform technologies, genetic engineering DNA replication and the other scientific techniques that define biotechnology are adapted to specific commercial uses. While market forces will decide what applications are pursued, we may expect that a geographic pattern of technology specialization reflects the localized nature of knowledge spillovers. Existing expertise in a region may define the transformation of generic scientific discoveries into specific specialized technological trajectories. Orlando (2000) and Autant-Bernard (2001) provide evidence that the ability to benefit from knowledge spillovers is conditioned on technological proximity: the effects of knowledge spillovers are greater for similar applications. This suggests

[13] These data are based on firms' reports of their research and product development areas. No measure of firm effort or success in these fields is provided.

[14] These firms are included in the BioAbility database have a product development agenda in biotechnology and are potential clients for firms who use the U.S. Company Database as a marketing tool.

that firms working on applications for which the region is specialized will realize a locational premium that will aid their growth.

Most analysis considers biotechnology as a homogeneous industry. Kenney and Von Berg (1999) note that early discussions of the computer industry relied on an aggregation of mainframe computers and personal computers. Yet, in retrospect there was substantial regional differentiation between these two sub-sectors which subsequently manifested in widely divergent growth trajectories. In sum, we may expect that the growth trajectory is endogenous to the technology trajectory. Thus the specific technological tools and the applications the firm develops is a function of regional capability. The growth of the cluster and the region, in turn, may be a function of the technology chosen.

[Table 5 about here]

Differences in Industry Composition

Table 5 presents more descriptive statistics on the characteristics of dedicated biotechnology firms and the industrial concentrations in the ten most prominent cities. Column 1 provides the average year founded for all the dedicated biotechnology firms, both in terms of mean (with standard deviation) and median. While we date the beginning of the industry to the early 1970s, these data suggest that the industry is in different stages of development in different locations. Column 2 presents average number of employees. Again, there is great variation, reflecting not only the age of firms but also the success of a few dedicated biotech firms. Column 3 presents the fraction of dedicated biotechnology firms that are either publicly traded or subsidiaries of other firms. The number of firms that are independently privately held is the residual fraction.

City-industry demographic data are provided for the time period 1997-2001: death rate, the number of firms that failed during the time period relative to the total number of firms in

1997; the merger rate: the number of firms that merged or were acquired over the time period relative to the population, and: the birth rate or the rate at which new firms were started relative to the 1997 existing base of firms.

Finally, the last column in Table 5 presents the ratio of dedicated biotech firms to what we term Anchor firms in the city[15]. For example, nationally, there were 1,491 dedicated biotech firms in 1997 and 356 Anchor firms using biotechnology in their existing product lines, for a ratio of 4.2. This contrasts to a ratio of 3 in Raleigh-Durham and 45 in Seattle. In sum, this descriptive analysis presents a picture of a geographically concentrated emerging industry that is

- dominated by a large number of new start-up firms dedicated to biotechnology with participation by a number of larger, more established firms;
- specialized in terms of product applications; and,
- heterogeneous between clusters with respect to rates of growth in terms of the number of firms, their size, age and type of financial backing.

Descriptive Analysis in Context

Much of the empirical investigation of the biotech industry has focused on academic research and linkages to university activity with mixed results. The work of Zucker and Darby and their co-authors examined the influence of academic star scientists prior to 1990.[16] Toole (forthcoming) notes that the focus on star scientists is due to the observation that biotechnology discoveries are characterized by tacit knowledge that is best communicated through face-to-face contact. They conclude that the location of biotechnology start-ups is influenced by the location of these star scientists. Zucker, Darby and Armstrong (1998: 152) interpret this to suggest that market mechanisms rather than knowledge spillovers account for the geographic concentration of the industry. But, they qualify their conclusions: "We suspect that more or better screens would identify top scientists in other aspects of modern biotechnology, which are not captured by genetic sequence discoveries, and would reduce or even eliminate the separate significance of

[15] As noted previously, the Anchor firms are more established firms with product lines that predate the biotechnology revolution but have current efforts involving biotechnology.
[16] Biotechnology star scientists are defined as those scientists with more than 40 genetic sequence discoveries in GenBank, the NIH genetic sequence database, through April 1990.

top-quality universities and federally supported university researchers (Zucker and Darby 1997)." This suggests that the findings may reflect the very beginning of the industry, which coincided with aggressive intellectual property licensing on the part of universities and a series of initiatives to leverage universities for local economic development. We may question the importance of universities to the continuing development of the industry, especially to the progress of specialized commercial applications. Thus while knowledge spillovers from universities may be important to early stage innovative activity, universities alone may not be sufficient to anchor a developing industry in a location.

Dasgupta and David (1987) highlight the distinction between the social organization of science and the more practical concerns of technology. Science, the pursuit of new knowledge, occurs primarily within the domain of the research university and is characterized by a priority-based reward system that emphasizes scientific publication. Technology, on the other hand, develops ideas from science for commercial markets. It is characterized by the pursuit of economic returns and its venue is for-profit firms. While it is appropriate to consider patents, publication and the location of star scientists in the earliest stages of firm formation – the science stage- we may expect that as an industry develops and science is translated into commercial applications the locational dynamics may change to emphasize industrial and technological attributes. While science resources may be most important in the earliest stages of the industry development, technology resources may become more important as the industry develops.

Evidence on the location of the biotech industry highlights the importance of the location of the chemical and pharmaceutical industry, especially their headquarters and R&D labs (Gray and Parker 1998; Orsenigo 2001:81-82; Zeller 2001). Orsenigo (2001:86) notes, "The pre-existence of a strong pharmaceutical national industry, with some large internationalized companies may have been a fundamental prerequisite for the rapid adoption of molecular biology" and further, the strength of the local science base is important but may not be the only factor in accounting for the development of the biotech industry. The biotech industry in Italy developed in Milan which did not have the top-rated academic research while Naples, an important academic center, did not develop a biotech industry (Orsenigo 2001:83)."

Innovative activity depends on knowledge and knowledge spillovers are geographically mediated. The next step is to understand causal relationships in agglomerations. Given that tacit knowledge resides in industrial firms, it would be useful to consider the role of industrial firms in agglomerations to explain these empirical observations and provide some testable hypothesis. The next section develops a theoretical model to account for these observations.

The Anchor-Tenant Hypothesis

Local economies are geographically bounded collections of firms. The question is, what forces promote the agglomeration of innovative activity and affect growth potential? Insights into agglomerations of firms may borrow from the real estate economics literature, which considers the problem of creating a viable economic unit in the design of the shopping mall (Agrawal and Cockburn 2002). Shopping malls are freestanding groups of retail stores under one roof, accessible primarily by car. They are designed to be self-contained shopping destinations that are isolated from other retail districts. Surrounded by parking space, they may be seen to resemble cities in their geographic isolation and dispersion throughout the landscape. Cities, like shopping malls, are the result of market forces. However, while it is difficult to observe the forces that shape agglomerations, the shopping mall problem is tractable. The problem for the profit-maximizing real estate developer is to rent space to a set of retail store tenants in order to generate a large volume of consumer foot traffic.

The typical shopping mall configuration is at least one large nationally recognized department store with an established clientele and then a diversified set of smaller, lesser known and more specialized stores.[17] The large national department store is known as the anchor tenant[18]. It is termed the anchor as it generates high volume mall traffic that provides a customer base for the shopping mall (Eppli and Shilling 1995; Pashigian and Gould 1998). If the anchor leaves the mall, the viability of the smaller stores is threatened (Gatzlaff, Sirmans, and Diskin 1994).

The anchor tenant's brand recognition creates an externality for the smaller stores who realize greater sales volume than they would in other locations. The value of this externality is reflected in higher rents the average tenant pays in comparison to the rent paid by the anchor tenant. This form of price discrimination reflects a willingness of the average tenants to pay a premium for location in the mall. Of course, capturing the value of externality is difficult but the existence of higher rents per square foot for the average tenant recognizes that a positive externality exists.

A regional economy may similarly benefit from the presence of large, technologically sophisticated entities that anchor local economies. Conceptually, the foot traffic generated in this case would be the volume of ideas. This may have particular importance for small firms in emerging industries which is associated with innovation. An anchor, in the form of a large, established firm may create externalities that contribute to benefit of agglomerations. Other studies have considered large established firms as part of an innovative infrastructure and found that the presence of related industry increases innovative output. In addition, Criscuolo, and Rajneesh (2002) among others adapt the concept of absorptive capacity to the geographic level to account for the ability of a region to benefit from R&D investments. The anchor tenant hypothesis proposes that a large firm may be a better anchor, in terms of economic success, for a developing industry than an equivalent number of small firms. Even if the stock of skilled

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[17] A larger mall, such as the Mall of America in Bloomington, Minnesota, has four national department stores: Nordstroms, Macys, Bloomingdales and Sears. For more information, see, http://www.mallofamerica.com/

[18] This problem is typically addressed by charging the anchor tenant a lower rent per square foot than the local stores. In this way, the local stores compensate the anchor (Pashigian and Gould 1998)

employees were equal under each regime, the large firm may exert a stronger influence. Organizational theorists have long recognized that there are size advantages to task coordination, efficiencies from internal economies of scale and scope and increased information flows. We can apply this theory to a regional economy to demonstrate how it may benefit from the presence of a large firm.

Certainly, the presence of a large established entity creates some of the well-known advantages of agglomeration economies such as pools of skilled labor and demand for specialized inputs that may benefit smaller start-up firms. In addition, an anchor may provide a pool of potential entrepreneurs who may take ideas out of the established anchor and form new firms. One measure of innovation that is important for early stage emerging industries is start-up firms. A stylized fact about entrepreneurship is that individuals do not relocate to start firms but instead use existing local contacts and networks to start their firms (Feldman 2001). This form of locational inertia indicates that regions holding stocks of potential entrepreneurs are more likely to be successful at promoting new firm start-ups and establishing new industries.

H1: The number of new start-up firms will be positively related to the number of anchor tenants in a city.

Anchor firms may further increase the viability of local firms through knowledge externalities. A large part of the knowledge fundamental to the application of a new technology is tacit: its non-codified nature makes it difficult to share without personal contact, direct inquiry and observation. As a result, distinct geographic patterns of firms and resources emerge according to a particular application and specific technology focus. In the case of biotechnology, there are generic technological breakthroughs, such as DNA replication, that define the industry and then a series of distinct patterns of innovative activities arises reflecting the localized nature of knowledge spillovers and industry development. Anchors may serve as customers for new start-up firms and as such may engage in user innovation networks (von Hipple 1994). Another stylized fact about start-up firms is that rather than rely on external financing or venture capital, start-up firms grow by selling services or engaging in procurement contracts for specialized products (Bhide 2000). The presence of an anchor may allow start-up firms to find relatively stable product niches that would allow firms to develop. This suggests that regional trajectories would develop.

H2: The technical specialization of the dedicated biotech firms will be positively related to the number of anchor tenants in a city.

The anchor tenant hypothesis suggests greater geographic concentration around anchors and this may vary over the industry life cycle. At the earliest stages of industry development, we may expect that universities and government labs serve as anchors. University patents, through licensing agreements, provide the technological underpinning of many new start-up firms. Much of the existing research has focused on defining the role of star scientists and university patents in the development of biotech. However, not all regions with strong research universities have been able to develop biotech industries. Universities appear to be a necessary but not a sufficient condition for the development of knowledge-intensive industries. The correlation between university research funding and patents, and company start-ups is weak and not statistically significant (cf. Barnes, Mowery and Ziedonis 1997; Siegel, Waldman, and. Link 1999; Raider 1998). In addition, there are examples where other referent institutions, such as government labs or large established companies incubated the biotech industry (Gray and Parker; 1998; Feldman and Francis 2002). This evidence suggests that there are underlying reasons why regions are not able to capture the benefits of their local science base, which have nothing to do with the proximity of a research university.

As the industry develops further, we may expect that more established firms focusing on applications related to biotech could serve as anchors. Locations lacking these anchors may be able to generate start-up firms but not be able to retain firms as they grow.

H3: Growth in dedicated biotech firms will be positively related to the number of anchor tenants in a city.

Anchor firms may create knowledge externalities that benefit the agglomeration and increase overall innovative output in the region. In the situation of a shopping mall, the market failure is addressed through rents. In the absence of such a transfer mechanism among firms, we may except that smaller firms would benefit from a location premium and this would result in a greater number of new start-ups and better performance.

Data and Empirical Results

This paper estimates two naive models to test hypothesis one and three. Our unit of observation is the city-industry reflecting the social organization of economic activity (Glaeser et al 1992). Descriptive statistics are provided in the Appendix.

With event count data, such as new firm births, a highly skewed error distribution is expected because the data are truncated at zero.[19] The number of new firm start-ups is assumed to be a Poisson process. To accommodate unobserved heterogeneity and time-dependence, we use maximum likelihood estimation.

Table 6: Negative binomial regression, number of births 1996 – 2001

	Model 1	Model 2
Number of Anchor Firms	0.2050 (0.0457)	0.0669 (0.0303)
Population	4.79e-07 (1.42e-07)	1.67e-07 (7.32e-08)
Number of Dedicated Biotech Firms		0.0307 (0.0051)
Constant	-1.4576 (0.2503)	-1.1694 (0.1864)
Alpha	1.8310 (0.4298)	0.5870 (0.2279)
Log likelihood	-187.164	-167.135
Number of Observations	163	163

Table 6 presents the results. The dependent variable is the number of new biotech start-up firms from each city for the time period from 1996 to 2001. Two specifications are tested for

[19] This means that no city-industry may have less than zero new firm start-ups.

163 cities that have activity in the biotech industry. Model 1 includes the number of anchor firms in the city, our main variable of interest.[20] This follows the definition introduced earlier: Anchors are more established firms that have a commercial interest in biotechnology. The model includes population as a control for urbanization economies. Since R&D expenditures and other independent variables that we may be interested in are correlated with city size. This simple model provides a first cut at estimating the relationship of anchor firms to start-ups. The second naive specification includes the number of prior dedicated biotech firms. After all, we may expect that places currently having a large number of new start-ups will engender additional rounds of start-up activity.

The results indicate that cities that have Anchors are more likely to have more new firm start-ups. There is a direct and statistically significant relationship between the number of biotech Anchor firms and number of new firm start-ups. As indicated by model 2, the number of dedicated biotech firms is also statistically significantly related to the number of start-ups as expected. The coefficient on the number of Anchor firms is twice that of dedicated biotech firms. While this is a naïve model, it provides evidence of a relationship of Anchor firms to the number of local start-up firms.

Table 7: Growth Rate Regressions: Percentage Change in DBF employment

	Model 1
Number of Anchor Firms	1.0834 (0.5322)
Population	1.91e-06 (7.42e-07)
Constant	-0.195 (0.3858)
R2	0.2653
Number of Observations	163

[20] Unfortunately, large diversified firms typically do not break down employment to the level of specific divisions or individual operations, either plants or R&D operations by city. The BioAbility data attempts to collect these numbers however upon verification we found that total firm employment is typically listed rather than place specific employment.

Next, to test the relationship of anchors to the growth of dedicated biotechnology firms, we estimate an OLS model with the percentage change in employment from 1997 to 2001as the dependent variable,[21] against the count of Anchor Firms in the 163 cities. Implicitly, we assume that firms operate in national product and factor markets. Population is again used as a control for urbanization economies[22].

The results indicate that employment growth in the city-industry is statistically related to the number of Anchor firms in the city. After controlling for city population, the presence of one additional Anchor firm would translate into greater than one percent growth in employment in dedicated biotechnology firms in the city.

Reflective Conclusions

The development of firms within regions is fundamental to our understanding of economic development, technological change, industrial evolution and economic growth. Firms located in geographically bounded knowledge rich environments are expected to realize higher rates of innovation, increased entrepreneurial activity, and increased productivity due to the localized nature of knowledge creation and deployment. This paper has provided an analysis of the development of the biotech industry, demonstrating increased geographic concentration, specialization and differential growth. The paper borrows from literature on real estate economics to offer some hypothesis about the composition of agglomerations. The concept of the Anchor – a large firm that provides both stability and traffic in ideas is related to the number of dedicated biotech start-ups and their growth. While these results are preliminary they suggest that regional industrial structure, product applications and technological orientation matter to innovative activity in an emerging industry. The ability of firms to derive economic value from knowledge is dependent on the firms' capabilities and strategic use of resources but the local

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[21] Since many dedicated biotech firms are not yet profitable it is not feasible to use data on sales or output. The employment in dedicated biotech firms is the sum of employment in all of the firms in the city.
[22] The number of dedicated biotech firms is highly correlated with the dependent variable and is not included.

environment shapes the firm's competencies, ability to absorb and utilize knowledge in the development of new products. Thus, the capabilities of firms and regions weave a tapestry of knowledge creation and commercial success.

The concept of a regional anchor provides a more detailed examination of the forces of agglomeration with implications for the development of emerging industries and regional specialization. In its earliest years, the biotech industry grew up around university star scientists who licensed innovations to companies. Today, there are many initiatives that attempt to build biotechnology clusters around universities using formal technology transfer mechanisms. Yet universities appear not to be a sufficient condition to promote an industrial cluster. Further, as biotechnology moves out of the lab, out of small single technology based start-ups and into new commercial applications, the location dynamics of the industry are evolving. The emphasis on star scientists is based on the observation that biotechnology discoveries are characterized by tacit knowledge that is best communicated through face-to-face contact. There is little doubt that this natural excludability played a role in the evolution of biotechnology, however, it depends on the specific discovery in question and it is likely to hold true for a relatively short period of time as valuable ideas and methods spread quickly (Toole, forthcoming). Industrial expertise and know-how are equally relevant and appear to be stickier and less easily transferred. The presence of Anchor firms may affect the specialized development of the industry within a region, a topic that requires further investigation.

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Table 1: Proportion of Dedicated Biotech Firms in Top Eight States: 1991, 1996, 2001						
	1991		1997		2001	
	N of Firms	Share	N of Firms	%	N of Firms	Share
California	197	23.2%	354	24.0	363	24.3%
Massachusetts	68	8%	157	10.6	162	10.8%
New Jersey	58	6.8%	78	5.3	82	5.5%
Maryland	57	6.7%	81	5.5	86	5.7%
Texas	41	4.8%	59	4.0	54	3.6%
New York	39	4.%5	64	4.3	66	4.4%
North Carolina	39	4.6%	82	5.6	98	6.6%
Pennsylvania	37	4.4%	67	4.5	68	4.5%
Total of Above	536	63.1%	942	63.7%	979	65.4%
Out of	849		1478		1497	
Total of Top 3	323	38.0%	592	40.1%	623	41.2%
Source: 1991 is from Dibner (1991) as reported by Prevezer (1997); 1997 and 2001 from IBI, author's calculations.						

Table 2: Distribution of Dedicated Biotech Firms by City					
Geographic Entity	State	1997		2001	
		N of Firms	Share	N of Firms	Share
Boston PMSA	MA	142	9.6%	142	9.5%
San Diego MSA	CA	107	7.2%	109	7.3%
San Francisco PMSA	CA	76	5.1%	70	4.7%
Washington, DC PMSA	MD/DC/VA	74	5.0%	77	5.1%
Raleigh--Durham MSA	NC	69	4.7%	88	5.9%
Philadelphia PMSA	PA/NJ	56	3.8%	47	3.1%
San Jose PMSA	CA	53	3.6%	50	3.3%
Seattle--Bellevue PMSA	WA	45	3.0%	42	2.8%
Oakland PMSA	CA	44	3.0%	55	3.7%
Minneapolis--St. Paul	MN	31	2.1%	27	1.8%
Orange County	CA	30	2.0%	28	1.9%
Houston PMSA	TX	29	2.0%	23	1.5%
Madison MSA	WI	28	1.9%	24	1.6%
Middlesex--Somerset MSA	NJ	26	1.8%	30	2.0%
Chicago PMSA	IL	25	1.7%	29	1.9%
New York, NY PMSA	NY	25	1.7%	27	1.8%
Baltimore, MD PMSA	MD	22	1.5%	25	1.7%
Source: Authors Calculations, 2000 Census Geography definitions used[23]					

Table 3: Within City Concentration of Firms and Degree of Specialization

N	% of City Firms	Location Quotient	Product Category
Boston, Massachusetts: Total of 142 firms			
67	42.41%	155.00	Therapeutics: 557 or 30.44%
28	17.72%	93.72	Clinical Diagnostics: 385 firms or 21.04%
14	8.86%	128.04	Cell Culture: 141 firms or 7.70%
9	5.70%	77.29	Immunological Products: 150 firms or 8.20%
8	5.06%	90.43	Medical Devices: 114 companies or 6.23%
5	3.16%	59.68	Environmental Testing: 108 firms or 5.90%
4	2.53%	35.66	Plant Agriculture: 145 firms or 7.92%
San Diego, California: Total of 107 firms			
53	49.53%	162.72%	Therapeutics: 557 or 30.44%
30	28.04%	133.26%	Clinical Diagnostics: 385 firms or 21.04%
13	12.15%	200.16%	Drug Delivery Systems: 111 Companies or 6.07%
12	11.21%	136.77%	Immunological Products: 150 firms or 8.20%
10	9.35%	121.37%	Cell Culture: 141 firms or 7.70%
10	9.35%	150.01%	Medical Devices: 114 companies or 6.23%
San Francisco, CA: Total of 76 Firms			
34	44.74%	146.97%	Therapeutics: 557 or 30.44%
20	26.32%	125.08%	Clinical Diagnostics: 385 firms or 21.04%
8	10.53%	128.37%	Immunological Products: 150 firms or 8.20%
7	9.21%	119.62%	Cell Culture: 141 firms or 7.70%
5	6.58%	108.38%	Drug Delivery Systems: 111 Companies or 6.07%
Washington, DC: Total of 74 Firms			
22	29.73%	97.67%	Therapeutics: 557 or 30.44%
17	22.97%	109.19%	Clinical Diagnostics: 385 firms or 21.04%
10	13.51%	175.50%	Cell Culture: 141 firms or 7.70%
10	13.51%	164.80%	Immunological Products: 150 firms or 8.20%
8	10.81%	178.10%	Analytical Testing Services: 111 companies or 06.07%
Raleigh—Durham, North Carolina: 69 Firms			
25	36.23%	119.03%	Therapeutics: 557 or 30.44%
17	24.64%	117.10%	Clinical Diagnostics: 385 firms or 21.04%
9	13.04%	209.37%	Medical Devices: 114 companies or 6.23%
8	11.59%	191.01%	Drug Delivery Systems: 111 Companies or 6.07%
8	11.59%	191.01%	Analytical Testing Services: 111 companies or 06.07%
8	11.59%	184.62%	Veterinary Products: 115 firms or 6.28%
7	10.14%	131.75%	Cell Culture: 141 firms or 7.70%
6	8.70%	109.79%	Plant Agriculture: 145 firms or 7.92%
6	8.70%	106.04%	Immunological Products: 150 firms or 8.20%
5	7.25%	122.82%	Environmental Testing: 108 firms or 5.90%

Table 3: Within City Concentration of Firms and Degree of Specialization

N	% of City Firms	Location Quotient	Product Category
Philadelphia, Pennsylvania: 56 firms			
29	51.79%	170.12%	Therapeutics: 557 or 30.44%
9	16.07%	76.39%	Clinical Diagnostics: 385 firms or 21.04%
7	12.50%	211.86%	Environmental Testing: 108 firms or 5.90%
6	10.71%	176.51%	Drug Delivery Systems: 111 Companies or 6.07%
6	10.71%	135.28%	Plant Agriculture: 145 firms or 7.92%
4	7.14%	87.11%	Immunological Products: 150 firms or 8.20%
4	7.14%	140.61%	Animal Agriculture: 93 firms or 5.08%
3	5.36%	377.26%	Biomaterials: 26 Firms or 1.42%

Table 4 : Location Quotients for Non-Prominent Cities, All Firms, by Product Type

	N	% of City Firms	Location Quotient	Product Category
Des Moines, IA	4	50.00%	984.25%	Animal Agriculture
Kansas City, MO	4	36.36%	579.04%	Veterinary Products
Atlanta, GA	4	22.22%	356.70%	Medical Devices
Nassau—Suffolk, NY	6	28.57%	348.43%	Immunological Products
Milwaukee, WI	4	17.39%	342.35%	Animal Agriculture
Portland, OR	4	20.00%	338.98%	Environmental Testing
Miami, FL	4	21.05%	337.92%	Medical Devices
Bergen--Passaic, NJ	4	19.05%	313.80%	Drug Delivery Systems
Baltimore, MD	6	23.08%	299.70%	Cell Culture
Salt Lake City, UT	4	22.22%	280.58%	Plant Agriculture
Middlesex—Somerset, NJ	6	13.95%	229.88%	Drug Delivery Systems
Houston, TX	4	12.90%	212.57%	Drug Delivery Systems
Orange County, CA	4	11.76%	193.82%	Drug Delivery Systems
Orange County, CA	4	11.76%	192.86%	Analytical Testing Services
Minneapolis--St. Paul	5	11.90%	191.09%	Medical Devices
Portland—Vancouver	8	40.00%	190.11%	Clinical Diagnostics
Bergen—Passaic, NJ	12	57.14%	187.72%	Therapeutics
Madison, WI	5	14.29%	180.38%	Plant Agriculture
New Haven, CN	6	54.55%	179.19%	Therapeutics
Chicago, IL	4	9.09%	178.95%	Animal Agriculture
Los Angeles, CA	7	36.84%	175.11%	Clinical Diagnostics

Table 5: Comparison of Characteristics of Dedicated Biotechnology Firms in Prominent Cities										
	DBF Characteristics			Corporate Organization		City-Industry Demography				
						Event / Firms in 1997				
	Year Founded		Number of Employees	Public (%)	Subsidiary (%)	Death Rate	Merger Rate	Birth Rate	DBF/Anchor
Boston	Mean	1988 (5.8)	107 (346.0)	41.5%	15.5%	0.070	0.141	0.197	142/19
	Median	1989	35						
Minneapolis	Mean	1984 (6.8)	61 (87.8)	61.3%	6.5%	0.032	0.129	0.032	31/11
	Median	1985	20						
Oakland	Mean	1987 (5.7)	258 (1141.3)	43.2%	11.4%	0.045	0.114	0.136	44/5
	Median	1988	35						
Philadelphia	Mean	1987 (7.9)	64 (115.1)	12.5%	19.6%	0.125	0.107	0.143	56/14
	Median	1987	28						
Raleigh-Durham	Mean	1990 (5.2)	20 (23.4)	14.5%	7.2%	0.145	0.072	0.478	69/23
	Median	1992	10						
San Diego	Mean	1988 (5.3)	89 (127.2)	39.3%	11.2%	0.056	0.047	0.215	107/7
	Median	1988	47						
San Francisco	Mean	1989 (5.2)	96 (363.0)	35.5%	11.1%	0.118	0.118	0.184	76/4
	Median	1990	25						
San Jose	Mean	1989 (4.8)	89 (101.7)	43.4%	17%	0.075	0.075	0.151	53/6
	Median	1990	50						
Seattle	Mean	1987 (6.3)	92 (158.3)	37.8%	20%	0.067	0.156	0.111	45/1
	Median	1987	29						
Washington	Mean	1985 (7.6)	83 (220.6)	29.7%	16.2%	0.068	0.054	0.135	74/6
	Median	1985	25						
National	Mean	1987(7.1)	79 (309.9)	31.5%	13.3%	0.079	0.087	0.158	1491/356
	Median	1987	25						

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Appendix: Description of the Data

BioAbility creates snapshots of the industry at specific points in time. It is a proprietary database that is market to companies who seek to sell products to the industry or conduct competitive intelligence. It is primarily a marketing tool.

The data do provide a comprehensive list of companies that participate in the industry at a specific point in time. One copy of the U.S. Company Database was purchased in July 1997. Another copy was purchased in July 2001. Company names were matched to create a panel. This simple statement underestimates the difficulty of creating a two-time period panel because this industry is very fluid and many firms change their names, merge or exist the industry. Verifying the data and status of the companies was a time consuming effort.

First, firms were classified as either dedicated biotech firms or Anchors. The criteria for an Anchor was that 1) the company was started before 1970; and 2) the company was a positive revenue stream from non-biotech product lines or 3) the firm was a wholly owned subsidiary or division of a non-biotech company. To reiterate, these firms are included in the BioAbility database have a product development agenda in biotechnology and are potential clients for firms who use the U.S. Company Database as a marketing tool.

For Dedicated Biotech .Firms (DBFs) there were several outcomes:

1.1.1. Firm is in continuous existence
    1.1.1.1. accounted for 18 name changes
    1.1.1.2. firms may relocate
1.1.2. New Entrants to the industry: these are counted as births
1.1.3. Exits from the industry
    1.1.3.1. Bankruptcies
    1.1.3.2. Movement out of biotechnology
    1.1.3.3. Mergers/Acquisitions

These data form the basis of the investigation.

Appendix Table: Correlation Matrix

	Anchor Firms	1997 DBFs	DBF Births	DBF Deaths	2001 DBFs	DBF employment 1997	DBF employment 2001	Population
Number of Anchor Firms	1.0000							
Number of 1997 DBFs	0.6651	1.000						
Number of DBF Births	0.6745	0.9199	1.000					
Number of DBF Deaths	0.6000	0.8948	0.8559	1.000				
Number of 2001 DBFs	0.6739	0.9977	0.9417	0.8848	1.000			
DBF employment 1997	0.5074	0.8633	0.7052	0.6920	0.8517	1.000		
DBF employment 2001	0.4937	0.8837	0.7431	0.7152	0.8750	0.9785	1.000	
Population	0.5321	0.4353	0.3147	0.3882	0.4198	0.4064	0.3817	1.000

Mean and Standard Deviation of Variables used in Regression

	Mean	Standard Deviation
DBF employment 1997	692.55	1898.56
DBF employment 2001	843.80	2295.44
DBF employment growth rate	0.624	2.64
Number of 1997 DBFs	11.28	23.16
Number of Anchor Firms	2.18	4.25
Number of DBF Births	1.43	4.19
Population		