Comments Welcome

Commercializing Tacit Knowledge

Fundamental Determinants of the Size and Location of Biotech Clusters[1]

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Abstract:

Public policies frequently identify biotechnology and information technology as "desirable industry clusters" that produce an abundance of well paying jobs of the future. This survey discusses the promise of biotechnology employment growth and appropriate policies that foster vibrant regional biotech clusters. I argue for two fundamental determinants of the size and location of regional biotech clusters: star scientists who transfer tacit knowledge to startups via joint collaboration, and research universities that serve as "anchor tenants." The hypothesis carries policy implications for biotech locational analysis as well as public policy. Optimal policies are derived and compared to existing policies at the US state level for 2008.

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1. Introduction

This paper examines the fundamental determinants of the size and location of biotech clusters. Biotechnology startups commercialize scientific discoveries in the fields of biology, agriculture, food sciences and medicine. The nature of these discoveries differs distinctly from innovations in other high tech industries, which feature garage-to-riches stories that gave rise to *Hewlett Packard* or *Apple*.[2] Biotech is different; its innovations are uniquely knowledge intensive. They require vast amounts of uncodified complexity and tacit knowledge that is usually embodied in the discovering scientist (Rosenberg 1982).

As a result, the transfer of technology in biotech is also uniquely focused on the discovering scientist, more so than in most other industries. It is direct and personal interaction that provides remarkable value to the discoverer, whose involvement is essential in the formative stages of any commercialization attempt (Klevorick et al., 1995). To gain access to innovations, and to transfer the scientists' knowledge, biotech firms often employ the innovator so that the diffusion of technology can take place within firm boundaries (Azoulay, 2004).[3] The remarkable characteristic of such firms is that they are tightly tailored to the discovering scientists, who often function as residual owners (Zucker, Darby and Brewer 1998). As a result, discovering scientists shape not only the commercialization of the innovation, but they also determine *where* biotech startups locate and *which* firms are (most) successful. The unique structure of biotech knowledge transfer is thus a fundamental determinant of the size and location of biotech clusters.

Curiously, the growth of US biotech clusters has run counter to traditional theories that predict the geography of economic activity. Economic geography posits that agglomeration forces should generate economies of scale that subsequently attract new firms near existing, similar clusters. The associated density provides a deeper applicant pool to firms, facilitates knowledge spillovers, but also imposes costs of urbanization.

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[2] Imagine rags to riches stories involving college graduates starting a vaccine company in their parents' garage.

[3] In a survey of 64 universities, Thurby and Thursby (2002) found that pharmaceuticals, biotech, and medical device industries are most likely to directly employ faculty.

None of the major biotech centers in the US grew anywhere nearby existing, major pharmaceutical clusters. Instead, major biotech clusters formed *only* in the immediate vicinity of major research universities, mostly in Cambridge and California. For example, in 2002, 50% of all publicly traded US biotech firms were located either in Cambridge or California, and 96% of these firms were located within 35 miles of major research institutions (Yarkin and Murray 2003, Mullin and Lacey, 2003). Even more striking is that Boston, currently one of the most important biotech clusters in the US, featured zero pharmaceutical corporations and only a few venture capital firms when the biotech industry emerged in the late 1980s (Gilding, 2008). Biotech clusters thus require a fresh look and a new approach to understanding the fundamental determinants of their size and location.

This survey explores the location dynamics of biotech clusters to understand their propensity to locate near scientists at major research universities. The goal is to derive relevant policy implications that support the formation and the vitality of biotech clusters. I report on a wealth of data which suggest that biotech clustering dynamics reflect the unique nature of biotech knowledge transfer, which requires in-person, lab-bench collaboration. This hypothesis is supported by an extensive literature that links the quality of scientists to the performance of biotech companies. Firms that are associated with so called "star scientists" are shown to be overwhelmingly more successful than biotech firms that collaborate with average scientists. As a result, biotech firms do not simply cluster around *any* university campus. Biotech clusters develop where biotech firms are relatively more successful, which is near major research universities, where star scientists conduct basic research in the life sciences.

There are, of course, alternative means of transferring technology. The specifics always depend on the industry and on the type of knowledge that is being diffused. For example, in information technology and computer science, commercialization is advanced through skilled students who move from advanced university training to private sector employment. In the engineering and chemical sciences, firm-sponsored (contract) research is commonly used to disseminate ideas. In other industries, knowledge is also diffused via patent applications, scientific papers, or personal interaction between scientists and firms at conferences. This survey focuses squarely on the fundamental determinants and unique characteristics of biotechnology diffusion.

1.1 Venture Capital and Other Proximate Causes

The informed reader may be surprised by my lack of emphasis on venture capital. Venture capital is clearly a key factor for biotech startups. However, the focus of this paper is on *fundamental* causes of the size and location of biotech clusters, not on *proximate* causes. Fundamental causes are *necessary conditions* that determine the fortunes of biotech clusters. Proximate causes do not, by themselves, deliver sizable biotech clusters in particular locations.

Local venture capital is most certainly key to a flourishing biotech cluster, but it is by no means the necessary determinant of size and location. For example, hardly any venture capital existed in the Boston area at the birth of the Cambridge biotech cluster. Instead it was the quality of the research universities and the number of star scientists in the area that subsequently attracted a vibrant venture capital community. So the mere abundance of venture capital is “only” a proximate cause, since it serves as the fertilizer. Fundamental causes provide the original impetus that gives rise to future growth.

Other proximate causes include the “culture” of a research institution, or the attitude of local scientists. Some universities may, for example, want to maximize the diffusion of ideas via open source technology rather than profits or local employment. At other universities, scientists and administrators may be risk averse and prefer the prospect of steady licensing income over risky returns from startup investments. The predisposition towards entrepreneurship is also important: the star-scientist/entrepreneur represents an unusual combination of two uniquely productive traits. Yet another, perhaps less important proximate cause relates to the number of bio science PhDs that are produced locally to provide sufficient skilled labor for the cluster. All of these factors matter, but the focus of this paper is on fundamental causes.

1.2. Data Caveats

The process of scholarly research requires that inferences are based on empirical regularities that are vetted and peer reviewed. Even peer reviewed data does not always address the problem at hand as effectively as authors and policy makers would like. The data may, for example, speak only to particular subsets of times or industries, or it may represent amalgamations of city, regional, state, national, or even international data. Each individual dataset must therefore be used with care, as is general practice in economics. I do not base my inferences on any one particular dataset; instead I seek to highlight commonalities and consistent patterns that are supported by an assembled body of evidence. To my knowledge, no better dataset(s) exists that could have been used to address the issue.[4]

2. The Economics of Star Scientists

Biotech firms cluster around major research universities where star scientists conduct basic research. The economic principles underlying location decisions equate marginal benefits and marginal costs to maximize the net returns. This section explores the specific benefits to employing star scientists and the costs associated with building biotech clusters near major research universities.

2.1 Defining Star Scientists

Star scientists differ from ordinary inventors in a number of important ways. They mentor fewer and brighter students, publish many more articles, generate many more citations, and produce a greater number of patents than the average scientist. In a database of biotech researchers covering 14 years and 183 economic regions in the US, only a tiny fraction of star scientists (327, or 0.7 percent of the sample) is responsible for an unusually large share of articles in the field (17 percent). The publishing productivity of these star scientists is a staggering 22 times greater than the average researcher's in the

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[4] In lively communication with Gerald Barnett (Director, Research Technology Enterprise Initiative at the University of Washington), I have become keenly aware of how difficult it is to provide comprehensive, objective, and comparative data to measure the factors that determine the location and commercialization success of biotech firms. Barnett's sense is that any given dataset, even in refereed papers, is easily challenged by practitioners in the field who understand the nuances of these statistics. For example, studies might focus on the success of biotech in terms of commercializing knowledge as measured by monetized patents. But universities may not optimize patenting dollars; instead they may simply seek to meet the Bayh-Dole mandate.[4] If a university seeks to maximize the social value and not the monetary return from a discovery, success measures of commercialization that relate only to monetized patents or local employment do not accurately reflect the actual goals and priorities of the university. Hence, the focus in this paper is only broadly on the fundamental determinants of biotech cluster location and size.

sample (Zucker, Darby, Armstrong, and Brewer, 1998).[5] It is not simply the number of articles, however, that matters for the successful commercialization of a biotech discovery. Quite to the contrary, article or citation counts fail to capture the success of biotechnology transfer as I detail below. The number and quality of articles allow us to *identify* star scientists, but the success of a discovery's commercialization within a startup is more complicated.

Initially, economists surmised that simple affiliation of a star scientist with a biotech firm was key. Audretsch and Stephan (1996) surveyed biotech startups' annual reports for names of star scientists as a measure of technology transfer. But by 1996, the biotech industry had matured sufficiently so that a simple reckoning of star scientist affiliation was no longer an indicator of firm value (Higgins Stephan and Thursby, 2008). It turns out that the fundamental determinant of the success of a startup is whether a star scientist had *joint publications* with scientists at the particular biotech firm. Coauthoring implies bench-level collaboration and provides an efficient means of transferring tacit knowledge from discovering scientists to biotech startups (Darby and Zucker, 2002 and Audretsch and Stephan, 1996).

2.2 The Effect of Star Scientists on Startups

The greater the number of joint articles, the greater is the discoverer's involvement in a biotech's product development. Zucker, Darby and Armstrong (1998) examine how the *intensity* of the relationship between star scientists and biotech firms affects startups' products in development, number of products, and employment growth. They find highly localized geographic knowledge spillovers from universities to biotech startups. More importantly, they show that the closer the cooperation between star scientists and biotech firms, the better the firm performs in terms of a) products in development, b) number of products on the market, c) time to IPO, d) IPO capital raised,

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[5] The star scientist data was collected under UCLA's "human subjects provisions," since it required obtaining the residences of scientists associated with journal articles. Correspondence with the authors revealed that the *UCLA Office of Protection of Research Subjects* does not allow the release of names from this database under the human subjects provision. The authors, at my request, have initiated an appeal with the UCLA Human Subjects Campus Review Panel. If the panel reverses its decision, I future updates of this paper will contain the full list of star scientists and their associated companies.

and e) employment. Most interestingly, a control group of biotech firms that simply located near leading research universities is shown to have gained no advantage.

Figure 1 quantifies the differences for biotech firms with or without star scientist involvement. Joint work between star scientists and biotech firms has a significantly positive effect on a broad range of firm performance measures. Relative to biotech firms with no joint articles, five or more joint articles generate a) significantly higher rates of citation than other articles by the same (firm) author, b) about five extra products in development, c) three additional products on the market, and d) more than 800 additional employees.

Figure 2 shows that at least one joint article is associated with double the number of biotech patents, products in development, and products on the market. If the technology transfer is intensive (e.g., more than 11+ articles are jointly coauthored), the biotech experiences a five-to-ten-fold increase in patents, product development, and products on the market. Per joint article, star scientists deliver patents, product development and products on the market at about five times the rate of joint papers between firms and average scientists. In addition, Darby and Zucker (2002) show that Biotech firms with deeper star involvement are able to go public significantly earlier and raise greater IPO proceeds than other biotech firms. Specifically, they find that one additional joint article reduces the time from founding to IPO by 24 percent, and raises IPO proceeds by $1 million.

Darby, Liu and Zucker (1999) determined that the market value of biotech firms increases because joint publications are associated with substantially greater commercial value of in-house R&D. Specifically, one joint article leads to a 7.3 percent (or $33 million in 2009 dollars) increase in the predicted market value of a firm relative to similar firms with no joint articles. Aptly put, Zucker and Darby (2007) mention that “direct involvement of the very best academic scientists in commercialization of cutting-edge discoveries is a key determinant of which firms will win the competitive race and which will fall by the wayside.” Aghion and Tirole (1994) provide a theoretical explanation as to why investors place a higher value on firms in which the research principals are deeply involved.

3. The Biotech Location Decision

Thus far we have presented three propositions. First, biotech discoveries contain an unusual amount of tacit knowledge that is best transferred in personal, lab-bench interactions. Second, the depth of the collaboration and tacit knowledge transfer is well proxied by joint articles between scientists and biotech firm employees. Third, the combination of a) quality of the scientist and b) the number of joint publications with a firm author are associated with increased performance of biotech firms as measured by a broad set of criteria ranging from stock market valuation to employment. Given the data presented in Section 2, it is useful to inquire where star scientists locate, prior to investigating where biotech clusters thrive.

Life science discoveries originate with basic research, which is generally conducted at major research universities. The more prolific a university is in life sciences, the greater the likelihood that a star scientist can be attracted. A working hypothesis, therefore, might be that biotech clusters locate close to star scientists, who in turn locate near major research universities. Figure 3 provides strong evidence of a correlation between the number of star scientists in a region and the number of new biotech firms. This correlation exceeds 0.8, which indicates a strong positive relationship between star scientist location and biotech startup location. But star scientists are certainly not the only determinant, since the effects of universities and the local startup ecosystem also contribute.

3.1 Effects of Star Scientists and Research Universities on Startups

This section seeks to quantify the individual effects that star scientists and major universities exert on biotech firms. The focus is specifically on performance criteria for biotech startup and "incumbents" (i.e., existing biotech firms that establish new biotech subunits). Zucker, Darby and Brewer (1998) find that the geographic distance to joint authoring star scientists and to major research universities is crucial to the performance of biotech startups. Their full model indicates that the presence of one additional star scientist in the region increases the mean number of biotech firms in a given year by 40 percent.[6] A top quality research university in the region increases the number of biotech firms by another 80 percent. In addition, Darby, Liu and Zucker (1999) indicate that geographic proximity of a top-quality university increases IPO proceeds by $0.6 million, and reduces the time to an IPO by 14 percent. These figures can be contrasted with the benefits from a round of venture capital financing, which adds about $0.6 million to IPO proceeds. These effects are summarized in Table 1.

Major research universities thus have a direct tangible effect on the size and location of biotech clusters. This effect is generated via the scientists that invent and commercialize technology. Audretsch and Feldman (1996), Jaffe et al. (1993), and Henderson et al. (1998) corroborate this evidence by identifying a direct "paper trail" of patent citations that are concentrated in companies located geographically nearby major research universities. One term to describe the fundamental source of biotech clusters is to label major research universities "anchor tenants" of biotech clusters. In the business economics literature, an "anchor tenant" is usually the first and leading tenant in a commercial center. In the context of the biotech cluster, I label the major research university an anchor tenant, since it uniquely enhances the productivity of local innovation systems and stimulates local industrial R&D. Above the term "major research university" is used in the singular, although all high performing clusters have several "major research universities." Just like the Mall of America (the US' largest shopping mall) does not have a single anchor tenant, top biotech clusters usually feature 3 or more major research universities.

Zucker and Darby (1998, 2007) even find that research universities are the most productive types of institutions that commercialize biotechnology. They find that the reliance on federal research institutes in Europe (as opposed to private/public research universities) generates less commercialization of biotechnology. Figure 4 shows that European star scientists are more likely to work at federal research institutes. Although there is a substantial number of stars located in Europe, fewer than 10 percent of them

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[6] The coefficient in the log linear Poisson regression in their Table 3, regression f is 0.282, which translates into a 40% effect using a fourth order Taylor Series expansion.

have joint articles with biotech firms.[7] In summary, the *type of knowledge* that is generated in biotech, the resulting *structure of knowledge transfer*, and the available empirical evidence all point to the university as the quintessential anchor tenant of biotech clusters.

There is also an interesting feed back loop that blurs the clear definition between the individual contributions of star scientists and major that universities. Excellent research universities can themselves create the conditions by which a scientist becomes a star in the first place. These conditions could include access to competitive funds, relief from teaching or other duties, supply of lab start up funds, existence of top grad students, support from senior faculty (other stars). In this sense, the star scientist is not only uniquely productive, but also serves as an indicator for the quality and other intangible characteristics of a program/university.[8]

4. Public Policy to Foster the Commercialization of Tacit Knowledge

Policy makers frequently target biotechnology and information technology as "desirable industry clusters" that produce the green, well paying jobs of the new economy (Coleman, 2006). Cortright and Mayer (2002) of the Brookings Institution label biotechnology as "*The Next Big Thing*" and highlight that "83 percent of local development agencies place biotech among their top two priorities."

Industrial policies designed to foster biotech clusters have had mixed success, however. Although 41 states actively subsidize bio clusters (Battelle 2008), only about a dozen major clusters exist**.** Given the fundamental determinants of the size and location of biotech clusters discussed above, it is possible to suggest policies that foster biotech clusters. These policies can be contrasted with relevant existing policies that states implemented in the past to support biotech.

4.1 The Seattle Cluster as a Reference Area

Before we start examining policies, it is helpful to establish a reference cluster where policies hold particular significance. The Seattle cluster was ranked ninth in the

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[7] There may be several reasons for this discrepancy. Perhaps it is simply that Europe does not have its version of the Bayh-Dole Act, or that federal research institutes are simply less productive than (non-) profit research institutes or universities that are supported by federal funds.

[8] I thank Gerald Barnett for this insight.

nation and was characterized as a “biotech contender cluster” (along with Austin, TX) in the Brookings report (Cortright and Mayer, 2002). By 2008, the cluster had lost its “contender” status; Battelle (2008) no longer ranks a biotech cluster in Washington state among the top 10 states with “large and specialized biotech sectors” (Battelle 2008). Instead, the Seattle metropolitan cluster is ranked thirteenth in Research/Testing/Labs, and Medical Devices employment.[9]

These rankings seem to identify that the Washington cluster is at a threshold, one where policy might be particularly effective in determining future fortunes of further decline or catch up. The ranking can be parsed even further into more detailed subcomponents to illuminate possible bottlenecks. The Brookings report shows that, compared to the leading US biotech cluster, the greater Seattle metropolitan area features about one third of a) the number of scientists, b) top research universities, c) NIH funding dollars, and d) biotech IPOs. However, the region produced only one fifth the number of startups, one seventh the amount of R&D alliances, and one fourteenth the number of patents.

The relative numbers of patents and startups seems unusually low, but the finding is confirmed by a study of the Milken Institute (Milken 2006). It suggests that the University of Washington ranks ninth in terms of publication impact, but only thirty-fifth in terms of the number of patents produced, and fifty-fourth (out of 125 top international research universities) in terms of the number of startups (Milken 2006). One reason for the comparatively small number of startups might be that Seattle houses only one sixth as many star scientists as compared to the leading biotech cluster (Figure 3).

4.2 Optimal Policies

Economic efficiency posits that public funds should target those fundamentals that drive outcomes in order to generate the greatest return on the dollar. According to the university/anchor tenant hypothesis detailed above, policies should targeted at a) attracting star scientists that collaborate with startups, and b) supporting the institutional framework that houses star scientists to facilitate the interaction between star scientists

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[9] It should be noted that the notion of “a cluster” may be too narrow. Cluster X may well cooperate with cluster Y in joint collaboration, but for the sake of reporting, only one of the clusters will receive credit.

and startups. This institutional framework is shaped by the Bayh-Dole Act, which provides the guidelines of technology transfer for federally funded research. Bayh-Dole delegates details to universities, however, allowing them to set their own standards. Below I discuss four key aspects in which university policies/cultures may differ that impact the propensity to generate startups. These aspects have been selected because they have been the focus of the empirical literature; however, it is unclear whether the set represent a comprehensive array of crucial differences (see Learner 2009).

First is the shared distribution of royalties between inventor and university. The more generous the licensing share that is offered to innovators, the smaller is the incentive of the innovator to be involved in the commercialization. A low licensing share incentivizes the innovator to work with a startup to commercialize technology and realize the invention's full monetary potential. Second, universities may differ in the extent to which they provide "incubators" (entrepreneurs in residence and startup funds) to "ripen" technologies in close proximity to the innovator. Perhaps "proof of concept" is also a good term for this incubation stage. It is easier to prove the commercial success of "ripened" technologies, which facilitates startup activity. Third, university-internal venture capital, or "bridge funding," may vary greatly across institutions. These funds support research that extends beyond the scope of government or and foundations dollars. Finally, universities differ profoundly in their willingness to take equity stakes in startups in exchange for patenting, licensing, or other up-front costs.

Of the four factors, Di Gregorio and Shane (2003) find that only a) the licensing structure and b) the university's willingness to accept equity stakes increase the startup propensity with statistical significance. When licensing royalties are too generous, discoveries are twice as likely to be licensed (inter)nationally rather than exploited in local startups. The willingness to take equity stakes triples the number of startups associated with a university's technology licensing office.

4.3 Policy Comparisons

Actual policies implemented to support the growth of biotech clusters differ dramatically across states. A complete list of Washington State's public subsidies for biotech is provided in Table 2. Washington provided $40 million in 2008 to match life science R&D (Battelle 2008). This implies strong support for existing biotech, but the policy is not directly targeted at attracting additional talent. Other states have similar subsidies. At the high end is Pennsylvania's $75 million in annual funding for Biotech research (Battelle 2008, Table 26).

Such broad subsidies may seem risky, in light of the small employment effects in biotech. Seventy-five percent of biotech companies employ less than 50 employees (OECD 2009, Table 2.4), and even in leading states, biotech employment does not constitute more than about 0.5 percent of total employment (Battelle 2008, Table 19). In Washington, biotech employment is 0.2 percent of King County employment, and biotech and pharmaceutical employment constitutes about one percent of Washington employment.

It is true that the present size of an industry should not necessarily determine whether it is a good target for public funds. More important may be the so-called *industry job multiplier*, which indicates how many additional jobs are created in the rest of the economy for every job in that industry. Biotech multipliers are comparatively small. Coleman (2006) suggests a two-to-one job multiplier, implying that each biotech job creates one additional job in the region. Sjoblom (2009b) instead suggests biotech multipliers that range from three-to-one to five-to-one for Washington state. Nevertheless, these estimates of job multipliers are smaller than aerospace and information technology multipliers for Washington state that range from four-to-one to eight-to-one (Sjoblom, 2009a, Conway, 2002, Sjoblom, 2009b).[10]

An additional consideration is that general subsidies also expose state dollars to the extraordinary risk that biotech firms or venture capitalists shoulder. Unlike few other industries, the biotech sector is characterized by an unusual degree of financial and scientific uncertainty (Ernst and Young 2009). For example, despite its healthy rate of annual biotech startups, the number of publicly traded firms and the number of firms in the industry has stayed roughly constant in the US since 2000 (Ernst and Young 2007). Turnover is high even in the Seattle area. An informal tally reports that about 20 percent

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[10] These figures seem to contradict policy makers who assert that "the next wave of the new economy is going to be in biotechnology; life science will drive our economy in the future as technology and software drove our economy in recent years" (Murray, 2009).

of biotech startups either folded or left Seattle in the past decade (Lyman 2009). In this case, subsidies to these firms constitute windfall profits to investors, not to the region.

Based on Lyman's estimates, Tartakoff (2008) suggests that biotech employment in the Seattle area may have actually declined in the past years due to the demise or sale of companies. The Bureau of Labor Statistics' *Quarterly Census of Employment and Wages* confirms that King County biotech (and pharmaceutical) employment has declined about three percent since 2001, shedding about several hundred jobs in the process. At the same time, Washington state biotech (and pharmaceutical) employment added about 1000 jobs, or 9 percent (see Table 3).

The above evidence indicates that broad, undirected subsidies are unlikely to be recouped in terms of employment or tax revenues. Thus, a targeted approach is highly desirable. Many states feature such tightly targeted subsidies. The Washington Research Foundation provides, for example, about $1 million in commercialization funds per year, which are earmarked to facilitate the transfer of technology from the university to the local private sector.[11] This type of targeted support should prove decisive in raising the vitality of the local biotech cluster, since it invigorates the interaction between (star) scientists and startups that has proven to be so crucial to the commercialization process. Thirty-three other states provide similar commercialization subsidies; Pennsylvania, at the high end, provides over $15 million per year (Battelle 2008, Table 33).

Many states have already realized the importance of star scientists and decided to initiate specific programs that target these individuals. The *Washington State STARS Program* provides funds to the University of Washington and to Washington State University to recruit outstanding researchers. In 2008, the state spent $430,000, and the current proposal is to increase the amount to $4.2 million for 2009/2010 (Table 2, and Battelle 2008, Table 30). Eighteen other states and Puerto Rico also have specific "*STAR*" or "*Eminent Scholar*" programs that are designed to attract and/or develop rising stars in biotechnology, although some of these programs are not limited to life sciences.

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[11] Strictly speaking, the Washington Research Foundation is not a state initiative, it is a non-profit. It is included here as part of the Battelle report.

Among states that limit their *STAR* programs to biotechnology, Massachusetts led with $8 million in 2008. Among the STARS programs that are not limited to the life sciences (as is the case in Washington state), Georgia's program is deemed to be the most successful. The *Georgia Research Alliance's Eminent Scholars Program* has recruited renowned scientists to Georgia's universities for a number of years, and supports 40 bioscience scholars at an annual cost of approximately $11 million. Other states allocated annual funds for STAR programs ranging in 2008 from $430,000 in Washington state, to $25 million Texas, $30 million in South Carolina, and $150 million in Ohio (Battelle Table 30).

It is the overall relocation offer that a star researcher receives which is the final determinant in relocation, not the individual dollar amount associated with any single dimension of the offer. Part of this relocation package is the quality of eminent research institutions that are nearby. However, these figures do highlight a difference in funding priorities across states. Clearly biotech R&D subsidies are pervasive across states. The industry itself, however, is neither as stable nor as employment intensive as other potential funding targets. The discussion above suggests that those subsidies targeted directly at attracting and retaining star scientists, together with sufficient support for a flourishing innovation ecosystem at universities, will provide the greatest return on the dollar.

5. CONCLUSION

This survey sought to identify the fundamental determinants of the size and location of biotech clusters. A body of empirical evidence was surveyed, which suggests that the *type* of knowledge acquired in basic biotech research is tacit and uniquely complex. It distinguishes biotech from other industries such as information technology. As a result, the knowledge transfer in biotech is particularly focused on the innovator and on the involvement of the researcher at the early stages of commercialization. A number of datasets and studies directly link the quality of the innovator to a broad range of performance measures associated with startups.

Star scientists are shown to have a direct, positive effect on just about every performance measure of biotech startups (see Table 1). It is no surprise then that these startups are usually built around the star scientist. As a result, these firms usually locate near the major research university that houses the star scientist who gave rise to the invention. This renders major research universities the “anchor tenants” of biotech clusters. Star scientists and major research universities are thus the fundamental causes of the size and location of biotech clusters. The culture of a research organization and the flow of venture funds are certainly important, too, but they constitute only proximate causes.

The high quality research university becomes the anchor tenant because it is *the* fundamental determinant of the number of star scientists and hence, the number of startups that a cluster is able to support. This is why biotech clusters have defied conventional theories of economic geography. They did not locate around existing pharmaceutical clusters, or near existing venture capital centers. Instead they grew organically around major research universities that housed large numbers of star scientists.

Many states have active programs in place to foster biotech clusters, but few are successful, and even fewer are targeted at the fundamental determinants of the size and location of biotech clusters. I discuss policies suggested by the empirical findings and survey existing state policies in the US. Subsidies that expose tax payer funds to the risks shouldered by venture capitalists are to be discouraged in an industry that is characterized by an unusual degree of firm turnover and marginal employment multipliers. Best practice subsidies are provided by a number of states that target “stars” or “eminent scholars,” although subsidy levels differ by several orders of magnitude.

Table 1
Intensity of Star Scientist / Firm Involvement and Biotech Firm Performance

Metric	Performance Measure
At least five joint articles between firms and star scientists	• Significantly higher rates of citation than other articles by the same firm author • About 5 extra products in development • 3 additional products on the market • 860 additional employees
One to ten joint articles between firms and star scientists	• 5 fold increase in biotech patents • Doubles the number of products in development • More than double the number of products on the market • Raises a biotech's IPO proceeds by $1 million • Reduces the time from founding to IPO by 24 percent • 7.3% ($33 million in 2009 dollars) increase in predicted firm market value
Relative to a joint paper with a top-100 scientist, a star scientist's joint paper with a firm author generates:	• 5 times as many patents • 5 times as many products in development • 5 times as many products on the market • About twice (5 times) the rate of joint papers between firms and top 100 (average) scientists
Geographic proximity to a top university	• Increases IPO proceeds by $0.6 million • Reduces the time to IPO by 14% percent • Increases the number of biotech firm startups by another 80% • One additional star scientist raises number of startups in region by 40%
Control groups	• Locating near a university does not generate extra firm benefits in the absence of star scientist affiliation • Affiliations with star scientists (even Nobel Laureates) without joint articles does not improve firm performance

Sources cited in text. 0.7 % of star scientists produce 17% of published papers in a biotech database; their publishing productivity was 22 times greater than the average researcher.

Table 2
Washington State Support For Biotech Commercialization

The Life Sciences Discovery Fund provides funding to in-state researchers with a goal of promoting life sciences competitiveness. Structured as a competitive grant program, it authorizes up to $350 million over 10 years ($40 million in 2008).
The STARS Program provides funds to the UW and WSU to recruit researchers. In the 2009 legislative session, $4.2 million was appropriated for the STARS program for the next two years. $430,000 was invested in 2008.
The Technology Gap Innovation Fund advances the development of commercially promising UW innovations that need to bridge the funding gap between academic research and a full-fledged commercial product or service. Grants of up to $50,000 are available. The Technology gap fund is funded through UW Royalty Income.
Cougar Gap Fund advances the development of commercially promising WSU innovations that need to bridge the funding gap between academic research and a full-fledged commercial product or service. $150,000 were available in 2006-2007; maximum awards are $50,000.
Washington Research Foundation provides support to universities and other nonprofit research institutions with commercialization of technology through gifts and grants for scholarship and research. FY 2008-2009 the fund disbursed $1.2 million dollars.
State Revolving Loan Fund Early Stage Commercialization of New Life Science Technologies (Proposed in 2009). The fund should advance technologies to help achieve their commercialization potential. State funding should match the first $250,000 invested by private entities in university-incubated startups
Tax Credits (Proposed in 2009) for companies that invest the first $1.5 million that a startup company raises.

Source: SB 6015 *Report and Recommendations fostering Washington's ecosystem of innovation: Life sciences and information & communication technologies,* Draft 3.0 2009

Table 3
Biotech and Pharmaceutical Employment 2001-2008
(King County and Washington State)

King County

Industry	2001	2002	2003	2004	2005	2006	2007	2008	Change in Employment 01-08	
									in percent	levels
NAICS 3254 Pharmaceutical and medicine manufacturing	1482	1563	960	999	935	1112	1030	950	-36%	-532
NAICS 334510 Electromedical apparatus manufacturing	2203	2484	2039	1786	1611	1612	1520	1569	-29%	-634
NAICS 334516 Analytical laboratory instrument mfg.	236	236	217	217	236	271	299	291	23%	55
NAICS 3391 Medical equipment and supplies manufacturing	1195	1310	1202	1237	1153	1324	1128	1285	8%	90
NAICS 541711 Private R&D in Biotechnology[1]	1823	1791	1799	1722	1811	1797	1810	1931	6%	108
Total	6939	7384	6217	5961	5746	6116	5787	6026	-13%	-913

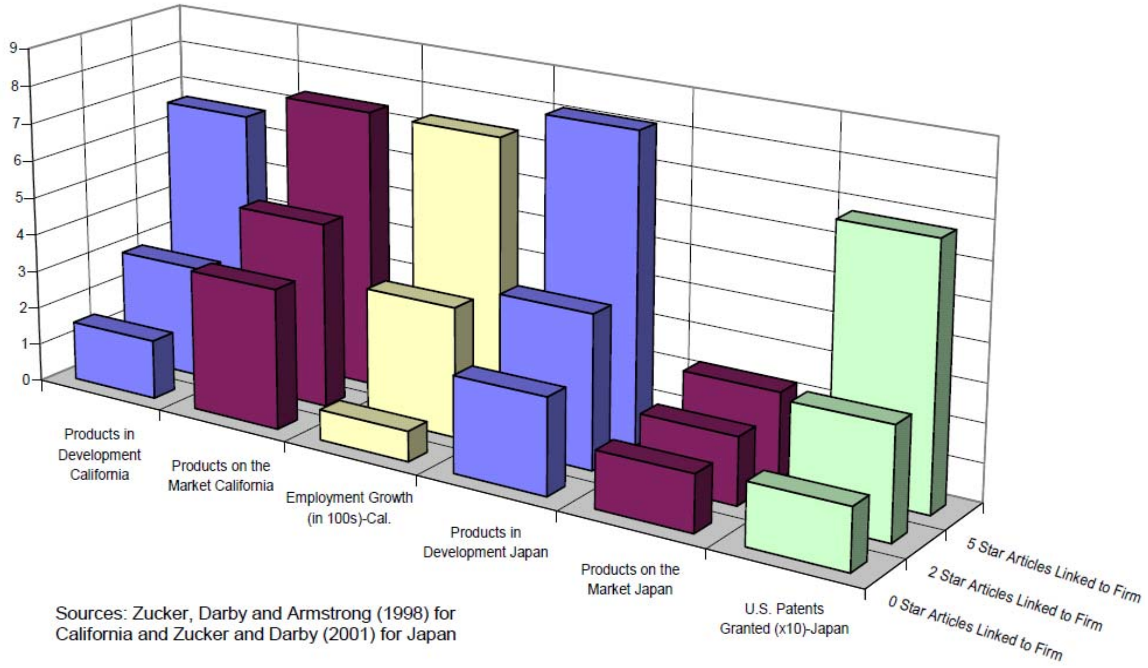
Washington State

Industry	2001	2002	2003	2004	2005	2006	2007	2008	Change in Employment 01-08	
									in percent	levels
NAICS 3254 Pharmaceutical and medicine manufacturing	2319	2389	1675	1795	1978	2293	2549	2491	7%	172
NAICS 334510 Electromedical apparatus manufacturing	4023	4413	4169	3778	3540	3582	3550	3619	-10%	-404
NAICS 334516 Analytical laboratory instrument mfg.	363	318	305	383	413	485	518	508	40%	145
NAICS 3391 Medical equipment and supplies manufacturing	3063	3543	3519	3423	3409	3476	3482	3612	18%	549
NAICS 541711 Private R&D in Biotechnology[1]	1875	2157	2247	2300	2383	2410	2679	2499	33%	624
Total	11643	12820	11915	11679	11723	12246	12778	12729	9%	1086

*The Table adopts the biotech sector NAICS definitions of Sjoblom (2009b). Source: Bureau of Labor Statistics

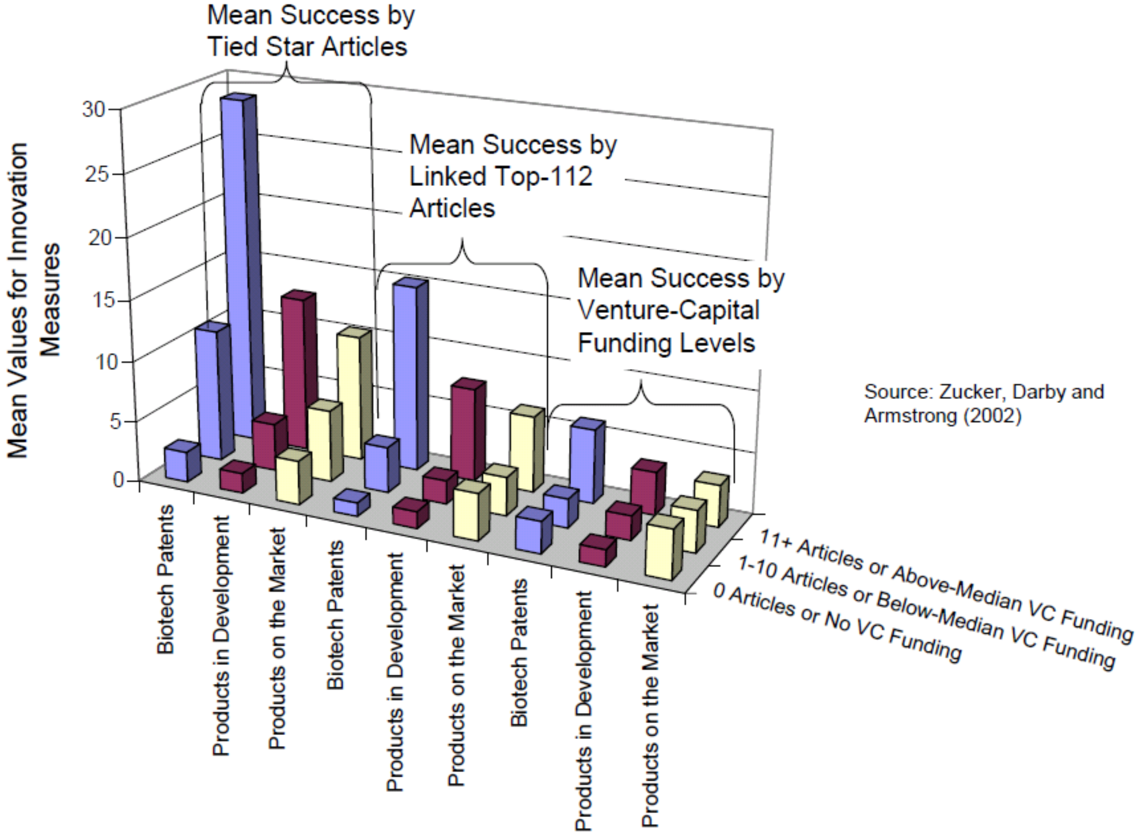
[1] Pre 2007 figures are estimates, based on 2007/8 data. Pre 2007, biotech R&D was included in *R&D in the Physical, Engineering, and Life Sciences*. Potential Life Science R&D not included in the post 2007 definition of *biotech R&D* are: agriculture research and development laboratories or services (except biotechnology research and development); Bacteriological research and development laboratories or services (except biotechnology research and development); Biology research and development laboratories or services (except biotechnology research and development); Botany research and development laboratories or services (except biotechnology research and development); Chemical research and development laboratories or services (except biotechnology research and development); Dental research and development laboratories or services; Environmental research and development laboratories or services (except biotechnology research and development); Experimental farms; Fisheries research and development laboratories or services; Food research and development laboratories or services (except biotechnology research and development); Forestry research and development laboratories or services; Genetics research and development laboratories or services (except biotechnology research and development); Health research and development laboratories or services (except biotechnology research and development); Industrial research and development laboratories or services (except biotechnology research and development);Life sciences research and development laboratories or services (except biotechnology research and development); Medical research and development laboratories or services (except biotechnology research and development); Veterinary research and development laboratories or services (except biotechnology research and development)

Figure 1
Impact of Star Scientist Involvement on Biotech Firms



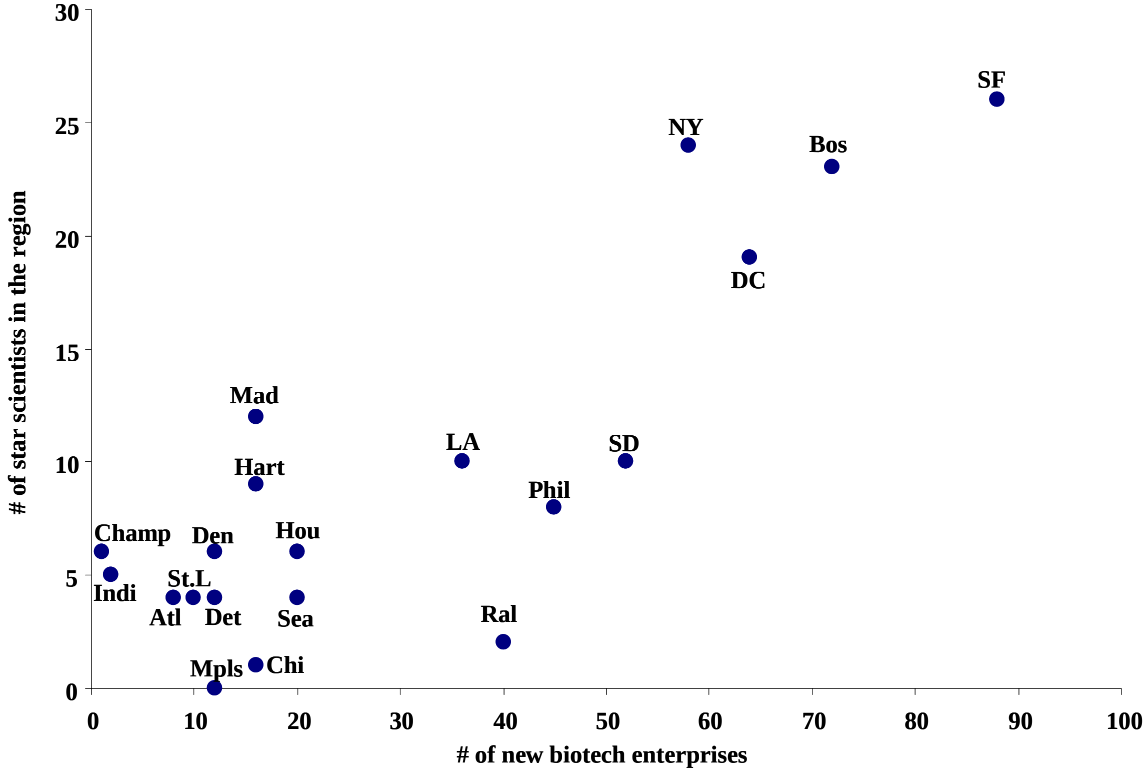
Sources: Zucker, Darby and Armstrong (1998) for California and Zucker and Darby (2001) for Japan

Figure 2
Impact of Joint Articles and Venture Funding on Biotech Firm Performance



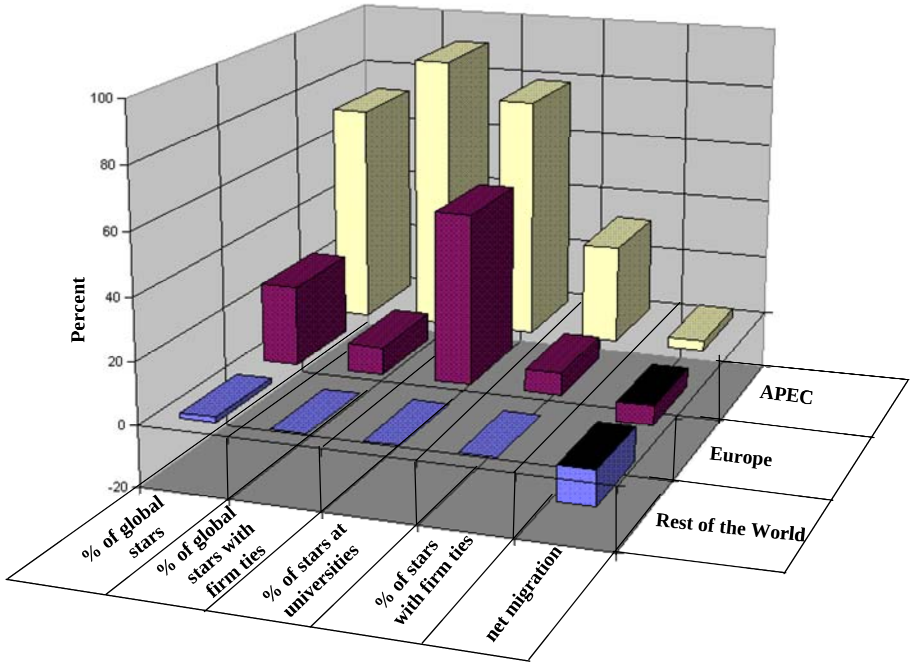
Source: Zucker, Darby and Armstrong (2002)

Figure 3
Biotech Startups and Star Scientists Across Regions



Source: Zucker, Darby and Torero (2002)

Figure 4
Universities, Net Migration, and Star Scientists in the Biotech Industry



Zucker and Darby (1998, 2007)

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