RESEARCH

TRANSFER OR GENERATION? BIOTECHNOLOGY AND LOCAL-INDUSTRY DEVELOPMENT

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This paper examines the local (regional) economic-development aspects of the emerging biotechnology industry and considers the relative importance of generation-oriented policies over transfer-oriented policies. Results from a study of the biotechnology industry in California are used to support the analysis. Basically, it was found that there is a complex industrial ecology associated with biotechnology. The firms choose to locate neither randomly nor entirely in order to be close to similar firms. Rather, it appears that they emerge in locations that have a nurturing biotechnology milieu. The presence of a critical biotechnology human-resource base creates its own dynamic, which diffuses into the surrounding medical, electronic, and other related industries. Thus, what develops is a local biotechnology-generation complex. Technology transfer's role seems to be subsidiary to the process of technology generation in the area.

During the last decade, two new themes have risen to prominence in economic-development policy. The first is the importance of technological innovation to economic competitiveness. Technological advantage has replaced resource-based comparative advantage as a strategic factor. As a result, governments throughout the world, whether national or provincial, now have some kind of organization that deals with technology policy. The second theme is an emphasis on the local dimension of economic processes. National economies are really a varied collection of local economies, each one contributing to and being affected by international economic trends. The departure point for this paper has been our recognition that technology and location are interrelated policy parameters in the field of economic development, at the national, regional, and local levels.

Policymakers, in essence, are beginning to focus their attention on technology policy as a means of addressing the challenges of local and regional economic development. This has been stimulated by the rise of the micro-electronics industry and the widely recognized sub-national regions such as California's Silicon Valley and Massachusetts' Route 128. With the emergence of biotechnology, the competitive stakes appear to have been raised. On one hand, the regions that were leaders in the emergence of micro-electronics-based industry also appear to have been the early leaders in biotechnology industry—with California once again being the frontrunner. On the other hand, many states, not to mention counties and cities, see biotechnology as a technological arena with greater scope than micro-electronics for providing them with the capacity to be competitive in industrial renewal and wealth generation.

In this paper we raise the following question: What scope is there for regions such as states and sub-regions such as counties, to successfully use technology transfer in the field of biotechnology as the foundation for economically competitive industries? We place special attention on the extent to which non-dominant regions vis-a-vis "high technology" might succeed in such a strategy. By technology transfer we mean the process whereby firms in a particular region receive new technology either from other regions via attraction of firms or locally from universities, scientific laboratories, or other firms.

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Because of the prominence of its high-technology industries, California is frequently looked to by analysts and policymakers for insights into the ingredients for industrial success in the new global technological environment. The leading role it has played in the emergence of biotechnology, given that the state has had little in the way of complementary industries such as the pharmaceutical and chemical, makes California an even more interesting case. We do not advocate simple emulation of California by other regions, but in view of the world attention the state's biotechnology industry has received, our study aims to provide some basic economic insights into the California biotechnology industry as a guide to local policy formulation.

By taking the premier biotechnology-industry region—California—as a case, *we develop the hypothesis that the generation of technological capacity rather than the transfer of technology is the most likely pathway for success in the development of biotechnology industry*. Technology transfer, whether interregional or intraregional, is likely to be feasible (at an economically significant level) only if a region already possesses the capacity itself to generate new technology.

Biotechnology is one of the fastest-growing and most important new industries in the United States. Its significance is in part measured by the number of firms and communities seeking to become the leaders in the field. There is little doubt that the industry has considerable potential.(1) In the words of the Ernst and Young biotechnology survey team, biotechnology is "America's most promising industry."(2) Whether biotechnology has the same economic or employment potential of the earlier microelectronics "revolution" is the subject of considerable speculation.(3) There are estimates that biotechnology is already more than a $3-billion industry while still in its infancy. It is predicted that by the turn of the century the biotechnology industry will be operating at a $100-billion level that encompasses activities ranging from health to metals and electronics.(4,5) In this paper we assume that the readers are familiar with the basic features of biotechnology as a field of technology as a new industry. Readers requiring more background information might read some of our other publications on this topic.(6,7)

STRATEGIC SEGMENTS OF THE BIOTECHNOLOGY INDUSTRY

While biotechnology is a set of related science-based techniques capable of being applied in existing industries, it is legitimate to view the firms and associated organizations involved in the development of these techniques as an industry, even though they also are defined as part of other conventional industries. The approach we adopted for our surveys and data analysis to deal with the industry's heterogeneity has been to classify biotechnology firms using the BioScan system, which subdivides the industry by market orientation into the general categories of diagnostics, therapeutics, agritech (agriculture, veterinary, and food/brewing), suppliers, and others (8), as defined in Figure 1. Thus, while recognizing that the subject matter of our research is highly heterogeneous, we nevertheless find it useful to describe the collection of organizations unified by their association with the development of biotechnology knowledge and applications as an industry.

The Survey

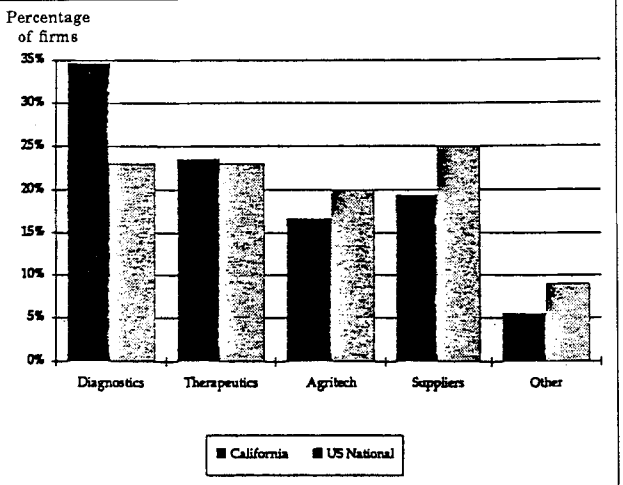
The survey instrument was administered for BIRG by the Survey Research Center of the University of California at Berkeley, and involved a 20-minute telephone interview of CEOs by trained professional interviewers. The population of firms was identified by BIRG from a variety of databases and published directories, and from other sources such as the California Industrial Biotechnology Industry Association. Strict procedures were employed to ensure that only firms actually operating as bona-fide biotechnology establishments were included. One-hundred-and-forty-five firms were listed in California, but BIRG was able to confirm only 114 as being in operation at the time of the survey (March 1988). Seventy-two firms participated in the survey (response rate of 63 percent). Respondents were asked a variety of questions about such matters as the size of their establishment, all of their locations, the strengths and weaknesses of California as a location for their firm, and human resources requirements.

The information reported in this paper was derived from a telephone survey of California bio-

Figure 1. Biotechnology Firm Types

Diagnostics:	Those human-health-care companies that design or develop products for a variety of tests for determining the presence of various health or disease states.
Therpeutics:	Those firms pursuing products that require extensive clinical testing for human or animal use, and that cure or reduce the effects or incidence of disease.
Agritech:	Firms that produce a large set of products for application in animal agriculture, plant agriculture, veterinary activities, the food/brewing industry, or for various environmental uses.
Suppliers:	Firms that produce specialized inputs for use in bioscience or biotechnology, such as biotechnology reagents, specialized biotechnology software or technical instruments for gene splicing.
Other:	Those firms that pursue some other type of application or deal with so many interrelated areas that they are difficult to classify.

Graph 1. Distribution of Biotechnology Firms by Main Market Orientation



Source: BIRG, 1988.

technology firms conducted in the spring of 1988 by the Biotechnology Industry Research Group (BIRG) of the University of California at Berkeley (see box), special analysis of California data from the Arthur Young national survey of biotechnology firms (9), and interviews of experts in commercial firms and universities conducted by the authors in the San Francisco Bay Area in the spring of 1987. A few of the firms we surveyed fitted into more than one category, but we were able to determine their dominant market orientation according to the BioScan classification system.(10)

California biotechnology firms, as indicated in Graph 1, concentrate their activities in human diagnostics and therapeutic products applications. Despite the importance normally attached to agriculture for the California economy, the state's biotechnology industry does not appear to place a particularly heavy emphasis on agricultural applications of biotechnology, relative to the national industry. This observation holds true for both the financial data and the firm-population data.(11)

A distinctive feature of the biotechnology industrial pattern in California is that the emphasis on research as the "product" of biotechnology is more pronounced than in other states.(12) It is also ironic to note that California has a relatively high emphasis on therapeutic pharmaceutical applications relative to the nation, given that the pharmaceutical industry is strongest on the east coast. The northeast has a high proportion of large pharmaceutical production firms which tend to rely upon smaller research firms for innovations in biotechnology. The presence of the United States Food and Drug Administration headquarters on the east coast probably reinforces this pattern. The location of these large-scale industrial pharmaceutical complexes is unlikely to change in the short term, since the entry cost of building similar facilities for manufacturing biomedical products for humans or animals is high. In spite of the clear link between the pharmaceutical industry and biotechnology, it is interesting to note that California is developing both a research and a production base. This fact suggests that industrial development through biotechnology might not necessarily require a pre-existing complementary industrial base in the local region in question. Gaining an appreciation of the factors that are stimulating this new economic activity in California may therefore be instructive to other states and communities.

THE ECONOMIC GEOGRAPHY OF CALIFORNIA BIOTECHNOLOGY

At a very general level of analysis, the partial distribution of biotechnology firms in California conforms to the high-technology spatial pattern discussed in the literature on technology location.(13) This literature essentially suggests that high-technology-enterprise locations are predominantly coastal and metropolitan, with very strong early histories in government contracting. The well-established link with government defense spending, as in the case of the microelectronic industry, however, is not in evidence for biotechnology. The primary source of government research funding in biomedical technology is the National Institutes of Health (NIH). The research and development resources of NIH are only a fraction of those of the Defense Department, and there is no clear biomedical industrial complex in California. Moreover, the necessity of the links between large-scale producers and smaller technology firms suggested by a number of scholars and commentators (14) does not account for the location of biotechnology firms in California, nor the regional distribution of these firms within the state or nation.

This evokes certain questions. Why has biotechnology emerged in California? Why do certain types of biotechnology firms select specific locations within the state? Has technology transfer been an important mechanism behind the state's success in this field, and, if not, what alternatives were there to technology transfer? The answers to these questions are important for determining what types of resources act as inducements for the development of biotechnology industry. A study of the California biotechnology industry is instructive for our purposes because, since the state was a leader in the field, the idea of relying upon the transfer of technology

from somewhere else had very little credence. The fact that many of the technology developments have happened within commercial organizations rather than within so-called "pure science" university laboratories lends even more plausibility to our suggestion that technology transfer is not likely to be central in biotechnology-industry development.

The state's biotechnology firms are largely located in the two great metropolitan regions in California: the greater Los Angeles-San Diego area in Southern California, and the San Francisco Bay Area in Northern California, with a small number in the periphery of each of these regions.

Within this general pattern, another more detailed pattern is apparent, with the firms clustering in a number of urban sub-regions: "Silicon Valley" in Santa Clara County (labeled "Santa Clara"), Upper Peninsula/San Francisco (labeled "San Francisco"), Berkeley/Emeryville/Oakland (labeled "East Bay"), San Diego (labeled "San Diego"), the combined city of Los Angeles/Orange (labeled "Los Angeles"), the Davis-Sacramento area (labeled "Sacramento"), and the outlying area around the greater Los Angeles metropolitan area (labeled "Southern California Periphery").

In order to ascertain the relationship between biotechnology and the existing regional economic-and-technological base within the local regions surrounding the seven biotechnology-industry clusters, we constructed a number of indices (Table One). Location quotients (LQs) measure relative employment density, and firm density indices (FDIs) measure relative business-establishment density. (See box on this page for LQ and FDI calculation methods and definitions.)

Table 1 shows that there is very little direct connection between the dimensions of biotechnology activity within a given sub-region of the state and the dimensions of either the total economic base or the specific high-technology base of that same sub-

Location Quotients and Firm Density Indices, California Biotechnology and High Technology, 1988

LQ = location quotient FDI = firm density index

Calculation Method

Hitech LQ = {(hitech employment in region)/(total California hitech employment)}/{(business employment in region)/(total California business employment)}

Biotech LQ = {(biotech employment in region)/(total California biotech employment)}/{(business employment in region)/(total California business employment)}

Biotech/Hitech LQ = {(biotech employment in region)/(total California biotech employment)}/{(hitech employment in region)/(total California hitech employment)}

Hitech FDI = {(hitech firms in region)/(total California hitech firms)}/{(business firms in region)/(total California business firms)}

Biotech FDI = {(biotech firms in region)/(total California biotech firms)}/{(business firms in region)/(total California business firms)}

Biotech/Hitech FDI = {(biotech firms in region)/(total California biotech firms)}/{(hitech firms in region)/(total California hitech firms)}

Definitions

Hitech firms: (High-technology firms) These are all firms within industries (3-digit SIC classifications) in which the percentage of engineers, engineering technicians, computer scientists, life scientists, and mathematicians exceeds the average for these occupations in the manufacturing sector. This definition is based upon the notion that "high technology" means that there is a high technical capacity in the workforce of an industry. This notion, and its corresponding definition, are drawn from the work of A. Markusen, P. Hall, and A. Glasmeier *(High Tech America: The What, How, Where and Why of Sunrise Industries* (1986). Boston: Allen and Unwin).

Hitech employment: (High-technology employment) This is total employment in the high-technology firms as defined above.

Biotech firms: (Biotechnology firms) These are all the firms identified in BIRG's 1988 survey of firms by that name. Strict procedures were employed to ensure that only firms actually operating as bona-fide biotechnology companies, as defined in the text of this paper, were included.

Biotech employment: (Biotechnology employment) This is total employment in the biotechnology firms defined above. Only jobs in commercial enterprises are included; public-sector and university jobs are not counted.

Sources of Data

All the data on biotechnology firms and employment is derived from BIRG's primary research and survey of California biotechnology firms during March 1988. All the data on high-technology firms and employment (accurate as of March 1988) was assembled from unpublished data files maintained by the California Employment Development Department (EDD), Sacramento, collected under the ES-202 program, and obtained from information provided to the state by employers as part of their unemployment insurance obligations. BIRG gratefully acknowledges the cooperation of the staff of EDD's Employment Data and Research Division.

Table 1. Location Quotients and Firm Density Indices, California Biotechnology and High Technology, 1988.

March 1988	East Bay	San Fran.	Santa Clara	Los Angeles	San Diego	Sacramento	So. Cal. Per.
Hitech LQ	0.685	0.247	3.172	1.173	1.044	0.361	0.557
Biotech LQ	3.233	1.346	3.199	0.535	2.008	0.505	0.670
Biotech/Hitech LQ	4.722	5.441	1.008	0.456	1.923	1.397	1.203
Hitech FDI	1.026	0.538	2.827	1.301	0.998	0.440	0.754
Biotech FDI	2.976	1.944	3.834	0.567	2.652	1.013	0.328
Biotech/Hitech FDI	2.902	3.613	1.356	0.435	2.657	2.303	0.435

Source: BIRG data (see box on previous page for calculation methods, definitions and primary sources)

region. The two sub-regions that are the most productive in generating a biotechnology industry, are the East Bay and Santa Clara. This is reflected in the biotechnology LQs, which rank the East Bay as having the highest density of industrial biotechnology employment, and in the biotechnology FDIs, which rank Santa Clara as having the highest density of biotechnology firms in California.

The high-technology location quotients for these two sub-regions, however, are quite different, with the Santa Clara sub-region exhibiting a density of high-technology employment almost five times that of the East Bay. Thus, while Santa Clara is strong in both biotechnology and high technology in general, thereby suggesting the possibility of some link between biotechnology and high-technology development in a region, the comparison with the East Bay shows that the size of the latter does not appear to determine the size of the former. This is reflected in the biotechnology/high-technology LQs (which measure the density of biotechnology employment in a sub-region against the high-technology employment in that sub-region, relative to the biotechnology and high-technology employment of the whole state). Santa Clara scores poorly by this measure.

The Los Angeles biotechnology cluster reveals even more strikingly the weak link between the magnitude of biotechnology-industry development and the magnitude of the existing economic or high-technology base in a region. The Los Angeles sub-region has the largest population, economy, and workforce by far of all the sub-regions—and it also has the greatest number of biotechnology firms and jobs of any of the sub-regions. Furthermore, Los Angeles is home to over twice as many high-technology jobs (about 509,000 in 1988) as Santa Clara (about 218,000 in 1988). Despite having a huge base economy, Los Angeles still scores relatively high in the density of its high-technology employment, second only to Santa Clara. Notwithstanding its large absolute proportions, Los Angeles is the weakest of all the metropolitan sub-regions as measured by its biotechnology and biotechnology/high-technology LQs. This suggests that the biotechnology industry thrives upon a special set of factors not necessarily required by other industries, whether high-technology industries or otherwise.

THE LOCAL TECHNOLOGICAL MILIEU

Biotechnology firms cluster in specific places. The Boston and San Francisco metropolitan regions are the best-known centers of the industry in the United States, although well-established biotechnology firms and research laboratories are scattered across the nation in such places as New York, New Jersey, Maryland, and North Carolina.(15) Notwithstanding its locational specificity, biotechnology operates in an international competitive environment.(16) Research and development opportunities are available in many parts of the nation and the world. For example, regions with a strong agricultural-science orientation can become major international competitors in very specialized crop, food, or fiber development utilizing biotechnology techniques. As a result, many new California firms that responded to our telephone survey have developed overseas research or manufacturing facilities in such places as Finland, Ireland, France, Japan, and Australia to take advantage of either research or production innovations in those countries.

The geography of biotechnology appears to be linked to government research facilities and universities, or to a combination of both. There are no independent biotechnology industrial nodes that are unrelated to an identifiable research center of national or international stature.

To gain some appreciation of the nature of the special factors upon which biotechnology firms thrive we sought information from firms in California about the determinants of their location decisions. Our field interviews during 1987 suggested that the constant exchange of new ideas and research information is essential to the continuous development of commercially viable biotechnology products. Proximity between firms allows for the development of special social and professional relationships within the bio-

Table 2. Factors Considered Important in Locating R&D Facilities (ranked in descending order of importance)

Factor	Percent of firms that considered these factors very important					
	Diagnostics	Therapeutics	Agritech	Suppliers	Other	Percent of total Respondents
1. Availability of qualified workers in the geographical area	68	77	73	64	50	69
2. Proximity of research universities and other research organizations	60	53	55	50	80	56
3. Cost of industrial space	24	41	64	50	30	39
4. County and city regulations	28	29	36	29	50	31
5. Amount of local taxes the company would have to pay	16	18	0	14	0	13
6. Wage rates	16	6	18	0	0	1
7. Proximity of major suppliers	8	0	27	14	0	1
8. Proximity of venture-capital and financial institutions	8	6	0	7	0	1
9. Amount of state taxes the firm would have to pay	16	12	18	7	0	13
Number of firms responding	25	17	11	14	4	71

Source: BIRG, 1988.

technology community. A majority of the 1988 telephone-survey respondents (59 percent) said that such relationships played an important role in stimulating new-product development. The core factors in decisions determining the location of biotechnology firms' R&D facilities, as shown in Table 2, are highly-skilled personnel and relationships with research institutions.

Table 3. Index of Collaboration between Universities and Biotechnology Firms

Region	Index
East Bay	0.54
San Francisco	0.53
Santa Clara	0.21
Los Angeles	0.21
San Diego	0.18
Sacramento	0.46
So. Cal. Periphery	0.05
California	0.36

Theoretical maximum = 1.0, theoretical minimum = 0.0

Source: BIRG, 1988.

Biotechnology companies rely heavily on university research programs for original theoretical research and for clinical testing. Table 3 presents an index which illustrates how universities act as magnet infrastructures for the incubation and development of the biotechnology industry. It suggests that the East Bay's strong biotechnology LQs and FDIs are related to the strength of university links held by its cluster of biotechnology firms.

The locational incentives that have traditionally formed the base of local economic-development programs, such as those concerned with cost of space, local regulations, wage rates, or taxes, are likely only to be marginal inducements for biotechnology

Table 4. Factors That Make California an Advantageous Location for Biotechnology Manufacturing

Factors (in Total Rank Order)	Percentage of firms that consider California an advantageous location					
	Agritech	Suppliers	Diagnostics	Therpeutics	Other	All Firms
Proximity to firm's R&D facilities	38%	38%	28%	43%	20%	35%
Availability of manufacturing facilities	19%	19%	11%	18%	10%	16%
Other factors	6%	13%	17%	18%	10%	15%
Proximity to markets	19%	6%	8%	11%	10%	11%
Regulatory environment	13%	0%	11%	4%	0%	7%
Cost of industrial space	0%	6%	8%	7%	0%	6%
Availability of raw materials	0%	13%	8%	0%	10%	6%
Distance from fed. regulatory agency	6%	0%	6%	0%	30%	3%
Competition from pharmaceuticals	0%	6%	3%	0%	10%	3%

Source: BIRG, 1988.

Table 5. Net percentage of Firms in Each Region That Consider Listed Factors in Deciding Location in California Advantageous for Biotechnology Manufacturing*

Locational Factor	East Bay	San Fran.	Santa Clara	Los Angeles	San Diego	Sacra-mento	So. Cal. Periph.
Availability of raw materials	80%	0%	0%	33%	0%	0%	0%
Proximity to markets	80%	33%	0%	-20%	-10%	0%	10%
Availability of manufacturing facilities	43%	0%	50%	-17%	25%	-50%	50%
Cost of industrial space	-77%	-62%	-50%	-91%	-13%	-67%	0%
Regulatory environment	-27%	-67%	0%	-9%	-33%	-50%	-50%
Proximity to firm's R&D facilities	75%	77%	75%	71%	71%	50%	100%
Other factors	0%	67%	50%	0%	43%	100%	0%

*"Net percentage" refers to the percentage of firms that find California to be advantageous less the percentage finding it to be disadvantageous; a negative score means that the majority of firms find location in California to be disadvantageous for biotechnology manufacturing.

Source: BIRG, 1988.

firms. As shown in Table 4, this also applies, at least indirectly, to manufacturing as well as research and development. Universities and related knowledge centers, such as teaching hospitals, major libraries, and similar resources, form the infrastructure for the biotechnology industry.

Knowing that the locational factors that are important to biotechnology firms for either research and development (Table 2) or manufacturing (Table 4) vary by market/product orientation, and knowing that market/product orientation varies between local regions, we decided to explore the extent to which the regional biotechnology clusters themselves vary in their locational concerns. Such information would provide clues as to the local milieu most likely to incubate a strong biotechnology-manufacturing cluster. These clues, in turn, may provide insights into the environmental factors that other regions outside California might need to cultivate in order to become more competitive in biotechnology. Data from our survey of California biotechnology firms which illustrate regional variations in factors that firms consider propitious for manufacturing are presented in Table 5.

A number of inferences may be drawn from Table 5. First, the degree to which California is perceived as an attractive location for biotechnology manufacturing varies a great deal between sub-regions. The biotechnology-industry cluster most satisfied with its location, when all the factors are taken into account, is in the East Bay, while the most dissatisfied is Los Angeles. Second, the mix of factors that are either attractive or unattractive for biotechnology firms, vis-a-vis manufacturing, also vary between sub-regions. Third, a sub-region that is attractive in some factors (e.g., East Bay: proximity of R&D facility, availability of raw materials) may be unattractive in others (e.g., East Bay: cost of industrial space). The general conclusion evoked by Table 5, and the foregoing discussion, is that regional competitiveness in biotechnology ought to be viewed very much as a problem of the competitiveness of local regions such as cities or urban sub-regions rather than just of larger regions such as states or groups of states. The strength and character of the local biotechnology milieux would appear to underlie the relative competitiveness of the regions.

CONCLUSIONS

There is a complex industrial ecology associated with biotechnology, and to some extent all emerging high-technology fields. Our research indicates that biotechnology firms, and probably all high-technology firms, are neither locating in a random fashion nor are they driven in their locational choices entirely by links with similar industries. Rather, it appears that biotechnology firms *emerge* in locations that have a conducive *biotechnology milieu.*

Our findings suggest that the presence of a critical biotechnology human-resource base creates its own dynamic, which diffuses into the surrounding related medical-, electronic-, and other scientific-applications industries. This synergistic or internal technology-generation dynamic continues to attract and develop new biotechnology entrepreneurs, who act as the seedbed of the local economic environment. Industrial biotechnology must be viewed from the economic-ecology point of view as a system of interconnected and interdependent components sustaining one another in a fragile economic environment. State and local policymakers, accordingly, ought to ensure the development of the entire system and not merely one of its parts. For instance, establishing a biotechnology industrial park will

probably not be worthwhile unless biomedical, environmental, and other research resources are developed to world-class standard in or near the industrial park.

Building policy that is this finely tuned to sectorial- and regional-resource differences is difficult at the state level. Regional politics within a state can make such an approach divisive. On the other hand, states like Massachusetts, Texas, and North Carolina have been successful with it. It is clear from our research that simplistic industrial recruiting approaches, or wishful thinking about the physical desirability of any location, or the presence of technology firms alone will not be enough to develop a biotechnology industrial base. Rather, localities interested in fostering biotechnology will need to design highly targeted programs that build a set of *cumulative technology assets* to form the base for this new industrial form.

To finish, we return to the question that motivated this paper: What scope is there for regions, such as states, or sub-regions, such as counties, to successfully use technology transfer in the field of biotechnology as the foundation for economically competitive advanced-technology industry? Our investigations suggest that, at least in the case of California, biotechnology industrial competitiveness arises from the generation of technological capacity within a rich milieu of people, knowledge, and institutions. Technology transfer, whether interregional or intraregional, appears to play a role only to the extent that it is subsidiary to the process of local technology generation. The choice is probably not between the two options themselves, but about which one to give the greatest priority.

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