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THE ECONOMIC GEOGRAPHY OF BIOTECHNOLOGY IN CALIFORNIA

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The Economic Geography of Biotechnology in California

An Exploration of Regional Form and Advanced Technology Industries

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Abstract

A lively debate has recently emerged over the relationship between technological change and urban and regional form. This debate, oriented somewhat to studies of electronics and information technology, has produced some rudimentary theory about new land-use patterns which appear to stem from the growth of "high technology" industry. Two questions are evoked by the present debate:

- will the regional form of one advanced technology industry necessarily be duplicated in another advanced technology industry?
- will the regional form of a particular advanced technology industry in one region be duplicated in other regions?

This paper tackles these questions by considering the place of one technological field which appears to be rising to paradigmatic status as the foundation of a new industry, biotechnology. Data on the biotechnology industry in California are examined to illuminate the issue of whether there are single or multiple regional forms which advanced technology industries might adopt. The paper finishes by developing a model for local economic development in biotechnology, which may also have some relevance to other advanced technology industries. Some policy implications are raised.

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1. Introduction: The Convergence of Regional Studies and Technological Innovation Studies

A lively debate has recently emerged over the relationship between technological change and urban or regional form. The rise of various "high technology" regions, particularly in the United States, has stimulated efforts by state and regional governments throughout the world to create or induce the formation of similar high technology industrial nodes in their own territory. A range of policy instruments have been devised for this purpose, including, for example, science parks, technology parks, innovation centers, training programs, taxation supports, targeted research funding, regulatory streamlining, direct subsidies to firms, or special financial schemes to aid small start-up high technology firms.[1]

Nowhere has the debate over technological change and regional form been more pronounced than in the case of biotechnology. Biotechnology, unlike other forms of new technology, does not appear to be dependent upon a single set of intellectual and financial resources. It is therefore widely perceived as having the prospects for universal development because of it not needing a prior industrial basis from which to emerge.[2] Using biotechnology as a case (and, in particular, the leading international example - the California biotechnology industry), this paper will explore the links between regional form and the emergence of industry based upon new technology.

The reasons for the emergence of the debate, together with the concomitant policy experiments, are varied.

First, technological innovation has become recognized as a determinant of the economic performance of industrial firms and sectors. Changing market conditions, increasing costs of industrial inputs, greater emphasis upon information flow as part of the economic process, more complex trading patterns, complex regulatory requirements, and sophisticated product-standard environments - to name some of the key pressures facing contemporary businesses - all place a

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[1] J. Schmandt and R. Wilson, eds., *Promoting High Technology Industry: Initiatives and Policies for State Governments* (Boulder and London: Westview Press, 1987); D. Whittington, ed., *High Hopes for High Tech* (Chapel Hill and London: The University of North Carolina Press, 1985); E. J. Blakely and P. Shapira, "Industrial Restructuring: Public Policies for Investment in Advanced Industrial Society," *Annals of the American Academy of Political and Social Sciences*, 475 (1984), 96-109; C. Carter, ed., *Industrial Policy and Innovation* (London: Heinemann, 1981).

[2] E. J. Blakely and N. Nishikawa, *The Search for a New Golden Goose: State Strategies for the Biotechnology Industry*, Working Paper #500, Institute of Urban and Regional Development, University of California at Berkeley, October 1989.

premium on an organization's competence in adopting and managing new technology.[3] Technology, furthermore, has come to be seen less as something which emerges miraculously out of the "black box" of science and engineering, exogenous to the processes of the economy, but rather as linked with the economic and managerial context.[4]

Second, growing international competition and interdependency in trade has given technological innovation an even higher profile in economic policy, and firms are increasingly forced to innovate in order to remain in business.[5] As a consequence, the strategic management of technological innovation has become an important component of corporate management, and most national and provincial governments have now established some kind of ministry which deals with technology policy.

Third, the phenomenon of "uneven development" has received considerable scholarly and political attention. It has long been recognized, at least since the classic work of Adam Smith or Karl Marx, that the generation of wealth tends not to be distributed evenly between either social classes or nations and regions within nations. This tradition in scholarship has witnessed a revival in recent years, fed by constributions from a number of disciplines, including political economy, geography, city-and-regional planning and sociology. Much of the recent literature is united by the theme that the economic disparity between regions and within regions increasingly exhibits structural features, changing in consonance with macro-economic structural changes in the national and international arenas.[6]

Fourth, uneven participation in state-of-the-art technology development and application has come to be seen as an explanation of uneven economic development between and within regions.[7]

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[3] K. Pavitt, ed., *Technical Innovation and British Economic Performance* (London: Macmillan, 1980); C. Freeman, *Technology Policy and Economic Performance: Lessons from Japan* (London and New York: Pinter Publishers, 1987); C. T. Hill and J. M. Utterback, *Technological Innovation for a Dynamic Economy* (New York: Pergamon Press, 1979); R. Rothwell and W. Zegveld, *Reindustrialization and Technology* (Harlow: Longman, 1985).

[4] N. Rosenberg, *Inside the Black Box: Technology and Economics* (Cambridge and New York: Cambridge University Press, 1982).

[5] J. Zysman and L. Tyson, eds., *American Industry in International Competition: Government Policies and Corporate Strategies* (Ithaca, NY: Cornell University Press, 1983); O. Granstrand, *Technology, Management and Markets* (London: Frances Pinter, 1982); R. Rothwell and W. Zegveld, *Innovation and the Small and Medium Sized Firm* (London: Frances Pinter, 1983).

[6] D. Massey and J. Allen, eds., *Uneven Re-Development: Cities and Regions in Transition* (London: Hodder and Stoughton, 1988); M. Marshall, *Long Waves of Regional Development* (London and Basingstoke: Macmillan, 1987).

[7] R. Oakey, *High Technlogy Small Firms: Innovation and Regional Development in Britain and the United States* (London: Frances Pinter, 1984); K. Chapman and G. Humphrys, eds., *Technical Change and Industrial Policy* (Oxford: Basil Blackwell, 1987); M. Sharp and C. Shearman, *European Technological Collaboration* (London: Routledge and Kegan Paul, 1987); M. White, H.-J. Braczyk, A. Ghobadian and J. Niebuhr, *Small Firms' Innovation: Why Regions Differ* (London: Policy Studies Institute, 1988); K. Willoughby, *Technology Choice* (Boulder and London: Westview Press, 1989); D. Maillat, ed., *Technology: A Key Factor for Regional Development* (Saint-Saphorin: Georgi Publishing Company, 1982); Office of Technology Assessment, United States Congress, *Technology, Innovation and Regional Economic Development* (Washington, DC: US Government Printing Office, 1984); C. Armington, C. Harris and M. Odle, *Formation and Growth in High Technology Firms: A Regional Assessment* (Washington, DC: Brookings Institution, 1979); R. Oakey, R. Rothwell and S. Cooper, *The Management of Innovation in High-Technology Small Firms: Innovation and Regional Development in Britain and the United States* (London: Pinter Publishers, 1988); F. E. I. Hamilton, *Industrial Change in Advanced Economies* (London: Croom Helm, 1987).

Some of the research dealing with this theme is based on particular technology-based industry sectors in particular places, such as micro-electronics in Britain,[8] but there is now a body of literature emerging which aims at producing general theory which transcends particular geographical regions, fields of technology and industry sectors.[9]

Fifth, as a consequence of the above themes emerging within scholarly debate, cities, or urban regions, have been recognized as the locus for leading-edge technological development, with a number of prominent "international" cities receiving the greatest attention: for example, the San Francisco Bay Area, the greater Los Angeles region, Cambridge in Massachusetts, Tokyo, or Cambridge and the M4 Corridor in Britain.[10]

Sixth, given the prominence of a relatively small number of "international" high technology cities, and their apparent interdependence, scholars have sought to understand both the way in which advanced technology industries affect urban form, and the way in which city structure affects the the prospects and form of local advanced technology industry complexes.[11] No generally accepted theory has yet been distilled from these efforts, but a consensus does appear to have emerged that a shift from an industrial style of economy (with its emphasis on the flow of resources and goods, and the accumulation of tangible assets) to an advanced-industrial style of economy (with its emphasis on the flow of information and the accumulation of knowledge) will be accompanied by a shift away from the "19th century agro-industrial" city form (with its simple center-periphery land-use patterns) to something more complex and probably more decentralized.[12]

The convergence of two fields of scholarly endeavor, technological innovation studies and urban-and-regional studies, has been mirrored in the national policy arena, with the emergence of deliberate efforts to create modern cities in which "high technology" and its associated social forms

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[8] K. Morgan and A. Sayer, *Microcircuits of Capital: 'Sunrise' Industry and Uneven Development* (Boulder: Westview Press, 1988).

[9] M. Storper and R. Walker, *The Capitalist Imperative: Territory, Technology, and Industrial Growth* (Oxford and New York: Basil Blackwell, 1989).

[10] P. Hall and A. Markusen, eds., *Silicon Landscapes* (Boston: George Allen and Unwin, 1985); A. Saxenian, "The Genesis of Silicon Valley," *Built Environment*, 9, 1 (1983), 7-17; M. Boddy, J. Lovering and K. Bassett, *Sunbelt City? A Study of Economic Change in Britain's M4 Growth Corridor* (Oxford: Clarendon Press, 1986); P. Hall, M. Breheny, R. McQuaid and D. Hart, *Western Sunrise: The Genesis and Growth of Britain's Major High Tech Corridor* (London: Allen and Unwin, 1987); Segal Quince Wicksteed, *The Cambridge Phenomenon: The Growth of High Technology Industry in a University Town* (Cambridge, UK: Segal Quince Wicksteed, 1985); S. Tatsuno, *The Technopolis Strategy: Japan, High Technology and the Control of the Twenty-first Century* (New York: Prentice Hall, 1986); A. J. Scott, *Metropolis: From the Division of Labor to Urban Form* (Berkeley and Los Angeles: University of California Press, 1988).

[11] A. T. Thwaites and R. P. Oakey, eds., *The Regional Economic Impact of Technological Change* (London: Frances Pinter, 1985); J. Brotchie, P. Newton, P. Hall and P. Nijkamp, eds., *The Future of Urban Form: The Impact of New Technology* (New York: Nichols, 1985); J. Brotchie, P. Hall and P. Newton, eds., *The Spatial Impact of Technological Change* (London: Croom Helm, 1987); P. Aydalot and D. Keeble, eds., *High Technology Industry and Innovative Environments: The European Experience* (London and New York: Routledge, 1988); J. A. Tarr and G. Dupuy, eds., *Technology and the Rise of the Networked City in Europe and America* (Philadelphia: Temple University Press, 1988).

[12] See, e.g., E. J. Blakely and R. J. Stimson, eds., *The New City of the Pacific Rim* (forthcoming).

may flourish. Examples include the "technopolis" regions in Japan, and the "multifunction polis" idea in Australia.[13]

In the wake of these developments some analysts have sought to produce general theory to descibe and explain the confluence of urban and technological change. Accordingly, the notion of a "high technology regional form" has appeared in the literature. Something of the spirit of this notion is reflected in the following extracts from a recent futuristic paper in this field, with a focus on North American cities:[14]

> A new national economic expansion driven by information-intensive technologies and the extension of global business services should be underway by the early 1990s. ... Cities will be more polynucleated, with the development of more multiple-use megastructures, and medium-density planned housing unit developments. ... Increasing leisure and use of telecommunications will facilitate increasing low-density developments in which residential, work, leisure activities ... and other local life-support activities are integrated, and increased emphasis on lifestyle and quality will ensure an increasing range and diversity of these developments within, at the periphery and beyond the urban area. The new affluence (for some) created by new technology will further add to this diversity and to the range of spatial development activities including glocal networks and virtual (global) cities. ... The cities of an advanced industrial society - the future metropoli - will be primarily engaged in indirect, and partially abstract, transactional activities, and may be hungry for collective rites to offset social fluidity, economic transience and electronic isolation.

This "high technology regional form" notion, although normally implied rather than explicitly articulated as formal theory, suggests that there is a typical pattern in the way urban/regional spatial structure and the structure of high technology industries coalesce. Walker observes this thematic development as follows:[15]

> [T]echnology has come to be viewed by the public as the key to the magic kingdom of regional development and national competitiveness. ... It is not surprising, therefore, that various kinds of technological determinism have found their way into the regional debate, such as the notion that high tech industries have a unique locational pattern, that R&D centers are crucial to local growth because of their innovative function, or that the product cycle dooms older industrial regions to imminent stagnation.

High technology industries seemingly emerge in cities exhibiting a certain kind of regional structure, with the development of those industries subsequently exerting influence on the region and reinforcing the spatial features which first led to the flourishing of those industries. The result

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[13] A. K. Glasmeier, "The Japanese Technopolis Programme: High Tech Development Policy or Industrial Policy in Disguise?" *International Journal of Urban and Regional Research*, 12 (1988), 6-8; I. Masser, "Technology and Regional Development Policy: A Review of Japan's Technopolis Programme," paper presented to Annual Conference of the *American Collegiate Schools of Planning*, Portland, Oregon, 5-7 October, 1989; T. Mandeville, "A 'Multi-Function Polis' for Australia," *Prometheus*, 6, 1 (1988), 94-106.

[14] G. Gappert, "Urban Issues in an Advanced Industrial Society," *The Spatial Impact of Technological Change*, edited by J. F. Brotchie, P. Hall and P. W. Newton (London: Croom Helm, 1987).

[15] R. A. Walker, "Technological Determination and Determinism: Industrial Growth and Location," *High Technology, Space and Society*, edited by M. Castells (Beverley Hills: Sage, 1985).

of these mutually reinforcing tendencies is that once a region becomes established as a high technology region it develops an international competitive advantage. Conversely, cities or regions which lack the appropriate structure find themselves increasingly bypassed by advanced technology industries and employment.

There are practical policy implications of this perspective. First, civic authorities and their advisors in high technology regions may adopt such a perspective in planning the "urban" infrastructure most fitting to the evolving industrial base of their economy (e.g., transport facilties, housing developments, zoning requirements, project development regulations, educational institutions, communications facilities, etcetera). Second, managers of advanced technology firms may be indirectly influenced by such theory when making decisions about the location of their activities. Third, regional and city policy makers wishing to improve the economic prospects of their region may look to such ideas to guide the adoption of policies aimed at altering their comparative economic advantage. It is therefore important for this incipient theory to be closely examined in the light of empirical evidence.

Much of the research upon which this "high technology regional form" theory rests has been based upon a small sample of supposedly paradigmatic regions (e.g., "Silicon Valley" in California and "Route 128" in Massachusetts) or upon multi-region studies of "high technology" in general, or information technology in particular. This paper raises the question of whether a simple "high technology regional form" notion is sustainable when a wider diversity of regions and industries is considered, or whether it is largely a reflection of the limited research base from which it has emerged. More generally, this paper poses the question of whether there are single or multiple regional forms which advanced technology industries might adopt.

This question is of great importance, for example, in discerning prospects for cities in the "Pacific Rim" region. The Pacific Rim is home to a great diversity of cities and countries, each with different economies, demographics, cultures, resources, and historical experiences. If multiple urban forms are possible with advanced technology industries, then the unique features of each Pacific Rim city become critical in the formulation of policy for the development of competitive metropolitan economies. If, on the other hand, there is only one "high technology regional (or urban) form" then attempted imitation of the leading regions, such as Silicon Valley, would appear to be the most advisable policy option.

In an effort to investigate this issue this paper will examine two specific sub-questions:

- will the regional form of one advanced technology industry necessarily be duplicated in another advanced technology industry?

- will the regional form of a particular advanced technology industry in one region be duplicated in other regions?

These sub-questions will be examined by considering the place of one technological field which appears to be rising to paradigmatic status throughout the world: biotechnology. Before doing so, however, the literature on high technology and regional form will be briefly reviewed.

2. The Literature on High Technology and Regional Form

The recent debate over factors determining the location of high technology industry emerged agianst the backdrop of traditional location theory for manufacturing industry. This body of theory, "Weberian location theory", points to transportation costs as the key determinant of optimal industrial location decisions, with firms weighing the relative transportation costs of access to raw materials, labor and markets.[16] Within this framework certain regions emerge as the most economic ones for certain industries or firms because of their apparent capacity to minimize net transport costs. Once firms cluster in one of these optimal locations, agglomeration economies emerge, thereby reinforcing the existing economic advantages of the location for the particular industry in question. Variants of this type of theory have held sway until quite recently and have been reinforced by the observation that, both in Europe and in North America, the dominant trend in industrial location has appeared to be one of spatial concentration.[17]

During the 1970s the capacity of traditional location theory to comprehensively explain industrial location patterns was increasingly questioned in the face of the decline of traditional industrial regions and the rise of new regions linked with emerging industrial forms. This was symbolized through reference to the rise of "sunbelt" cities based upon "sunrise" industries.[18] In contrast to the perceived general pattern of the previous half century, spatial dispersion emerged as the new emphasis in industrial geography. It appeared that throughout the industrialized world *dispersion* was superseding *concentration* as the key trend in industry location, and that this new trend also extended beyond the boundaries of the main industrialized countries into the Newly Industrialized Countries of the Pacific Rim.[19]

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16 This approach derives from the work of A. Weber in the 1920s (*Theory of the Location of Industry* [Chicago: University of Chicago Press, 1929]).

17 See "An Overview," in *High Technology Industry and Innovative Environments: The European Experience*, edited by P. Aydalot and D. Keeble (London and New York: Routledge, 1988), pp. 1-2.

18 See: D. C. Parry and A. J. Watkins, eds., *The Rise of Sunbelt Cities* (Beverly Hills: Sage Publications, 1977); B. L. Weinstein and R. E. Firestine, *Regional Growth and Decline in the U.S.: The Rise of the Sunbelt and the Decline of the Northeast* (New York: Praeger, 1978); L. Sawers and W. K. Tabb, eds., *Sunbelt/Snowbelt: Urban Development and Regional Restructuring* (New York: Oxford University Press, 1984). Cf., B. Bluestone and B. Harrison, *The Deindustrialization of America: Plant Closings, Community Abandonment, and the Dismantling of Basic Industry* (New York: Basic Books, 1982).

19 M. J. Breheny and R. W. McQuaid, eds., *The Development of High Technology Industries: An International Survey* (London: Croom Helm, 1987); D. Keeble, *Industrial Location and Planning in the United Kingdom* (London: Methuen, 1976); M. Castells, *High Technology, Economic Policies and World Development*, Working Paper #18, Berkeley Roundtable on the International Economy, University of California at Berkeley, May 1986.

Technological change emerged as a variable intimately linked with these economic and industrial-geographic changes. The development of new technological products and processes (particularly in the area of information handling and communications) was seen to provide the means for overcoming traditional physical or economic constraints to the spread of industrial activity, both between cities and within cities. Some commentators have sought to explain this by minor modifications to traditional regional growth and indutrial location theories.[20] Others have sought to introduce new concepts, such as that of the "informational city", whereby "space" is construed as the flow of information rather than as a geographical place.[21] In other words, the use of advanced technology is argued to enable decentralization of many industrial activities from the core to the periphery, while still maintaining the possibility of control and coordination from the center. Castells summarizes the new perspective as follows:[22]

> The most direct impact of high technology on the spatial structure concerns the emergence of a new space of production as a result of two fundamental processes: on one hand, high technology activities become the engine of new economic growth and play a major role in the rise and decline of regions and metropolitan areas, according to their suitability to the requirements of high tech production; on the other hand, the introduction of new technologies in all kinds of economic activities allows the transformation of their locational behavior, overcoming the need for spatial contiguity.

Thus, by the use of information technology, firms are able to concentrate functions of the organization while simultaneously dispersing the total organization by locating various parts of its activities in geographical locations best suited to each respective function or the organization's overall strategic goals. Some scholars have applied this insight to inter-metropolitan location decisions,[23] and some to intra-metropolitan location decisions.[24]

Despite the purported "footlooseness" of high technology industries, such industries have in fact emerged in certain key geographical regions, the most famous of which is in Santa Clara county in California ("Silicon Valley"). Worldwide, the development of high technology regions has been rather uneven, with the result that much debate has emerged over just how feasible it is

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[20] See, J. Rees, ed., *Technology, Regions, and Policy* (Totowa, NJ: Rowman and Littlefield, 1986).

[21] M. Castells, *Towards the Informational City? High Technology, Economic Change, and Spatial Structure: Some Exploratory Hypotheses*, Working Paper #430, Institute of Urban and Regional Development, University of California at Berkeley, August 1984.

[22] M. Castells, "High Technology, Economic Restructuring, and the Urban-Regional Process in the United States," in *High Technology, Space and Society*, edited by M. Castells (Beverly Hills: Sage Publications, 1985), p. 12.

[23] R. Gordon and L. Kimball, *Industrial Structure and the Changing Global Dynamics of Location in High Technology Industry*, Working Paper #3, Silicon Valley Research Group, University of California at Santa Cruz, 1986.

[24] A. J. Scott, "Industrial Organization and the Logic of Intra-Metropolitan Location: I. Theoretical Considerations," *Economic Geography*, 59, 3 (1983), 233-250; E. J. Blakely and R. H. Fagan, *Metropolitan Strategy in Sydney: Employment Distribution and Policy Issues*, Monograph #36, Institute of Urban and Regional Development, University of California at Berkeley, 1988.

for more than a small number of such regions to thrive.[25] The phenomenon of high technology regions has once again raised the theme of industrial concentration into prominence. Given the evidence of some urban areas emerging as clear leaders in high technology, and given that early entry into the use of such technology may provide a competitive economic edge to those urban areas, some commentators have argued against the view that the wide uptake of high technology will diminish the importance of geographic location for industries. The idea that new technology is likely to entrench the dominance of a handful of principle world cities is now quite established in the literature.[26]

The existence of high technology regions has evoked many attempts to create profiles of such regions in the hope that they might form the basis of fruitful policy initiatives by city and regional governments. Saxenian reports that the following features generally emerge from such studies as definitive parameters of high technology regions: (1) a high caliber research university to ensure a science-base and a supply of scientists and engineers; (2) an ample supply of venture capital to fund new firms; (3) public investment devoted to research and procurement of new technologies; (4) a quality of life able to attract and retain footloose highly-qualified professionals; (5) the absence of trade unions; (6) an industrial park to house start-up firms; and, (7) adequate infrastructure to ensure efficient transportation and communication linkages.[27] Saxenian ryely observes:[28]

> The underlying message - though rarely stated - is that once these prerequisites are assembled innovation and growth will follow. Like a souffle which exceeds the size of the initial ingredients, a region endowed with the proper mix of institutional and economic resources will be the lucky recipient of rapid high tech growth.

Much of the literature on the nature of these high technology regions also appears to have an underlying assumption that there is such a thing as a typical high technology region; or, that with enough research, it might be possible to develop a single universal law of high technology development, capable of accounting for the evolution - or non-existence, as the case may be in some places - of high technology regions.

Some excellent empirically grounded efforts at building general theory in this field have recently been published. One line of research seeks to explain the geographic concentration and dispersion of high technology industry in a dynamic way by using product-profit cycle theory;

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[25] A. Glasmeier, P. Hall and A. Markusen, "Metropolitan High-Technology Industry Growth in the Mid 1970s: Can Everyone Have a Slice of the High-Tech Pie?" *Berkeley Planning Journal*, 1, 1 (1984), 130-142.

[26] M. Moss, "Telecommunications and International Financial Centres," in *The Spatial Impact of Technological Change*, edited by J. F. Brotchie, P. Hall and P. W. Newton (London: Croom Helm, 1987), pp. 75-88.

[27] A. Saxenian, *The Cheshire Cat's Grin: Innovation, Regional Development, and the Cambridge Case*, Working Paper #497, Institute of Urban and Regional Development, University of California at Berkeley, April 1989, p. 2.

[28] *Ibid.*

thus, during early stages of the cycle, high technology firms need to cluster in high technology regions, but this requirement declines in importance as the industry or firm matures, and dispersion takes place.[29] Another line of resdearch views high technology firms as involved in networks of transactions, with some firms highly disintegrated functionally and some highly integrated, reflecting the relative costs of internal and external transactions. Accordingly, high technology regional nodes ("technopoles") emerge as the spatial convergence of vertically disintegrated producers under conditions of uncertainty.[30] The scholars responsible for both of these groups of studies, however, while assembling some evidence for the predictive power of their respective theories, have also been led to the conclusion that individual industries, whether high technology industries or otherwise, each exhibit special characteristics, with likely different spatial tendencies. It follows that a series of studies are called for, to identify possible variations in the urban form of advanced technology industries, both between regions and between specific high technology industries.

In summary, existing academic literature on high technology and industrial location contains two themes in tension with each other. On one hand, there is a presumption that there is a typical urban/regional form associated the phenomenon of high technology regions. On the other hand, there is some evidence that these may vary in certain ways from case to case. This theoretical tension is yet to be finally resolved. This paper will further the debate by providing evidence from the case of biotechnology in California.

3. The Basics of the California Biotechnology Industry

"Biotechnology" is a new word associated with a set of techniques based upon the application of modern biological science. When biotechnology is defined in its broadest sense, as practical or industrial processes that involve biological systems, it is as old as cheese making, brewing, composting or pickling. Scientific advances within the last two decades, however, have led to the development of some new biotechnologies which present potentially radical changes in the scope for artificial manipulation of biological systems. It is this particular set of modern

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[29] A. Markusen, *Profit Cycles, Oliogopoly and Regional Development* (Cambridge, MA: MIT Press, 1985); A. Markusen, P. Hall and A. Glasmeier, *High Tech America: The What, How, Where, and Why of the Sunrise Industries* (Boston: Allen and Unwin, 1986).

[30] Leading work along these lines is being conducted by A. J. Scott and colleagues at UCLA: Scott, "Industrial Organization", *op cit.*; A. J. Scott and D. P. Angel, "The US Semiconductor Industry: A Locational Analysis," *Environment and Planning* A, 19 (1987), 875-912; A. J. Scott and A. S. Paul, *Industrial Development and Regional Growth in Southern California, 1970 - 1987*, Working Paper, Institute of Industrial Relations, University of California at Los Angeles, (forthcoming); A. J. Scott, *New Industrial Spaces: Flexible Production, Organization and Regional Development in North America and Europe* (London: Pion, 1988).

biotechnologies which has generated the recent flurry of commercial experiments more popularly known as "biotechnology".[31]

Modern biotechnology draws upon at least three distinct fields of scientific and technical endeavor: recombinant DNA technology (often known as "genetic engineering"), cell culture technology (or, in vitro cell manipulation technology), and monoclonal antibody technology.[32] Some commentators also include protein engineering, microbial fermentation of enzymes, and "bioinformatics" (the convergence of biotechnology and information technology).[33]

While much debate exists over what exactly constitutes "biotechnology", in this paper the term will be employed to refer to the narrower spectrum of technologies which have been derived from modern biological science within the last 20 years or so and which are based loosely upon the fields of endeavor just listed.

When applied in practical or commercial settings these technologies can be used for such purposes as creating new kinds of drugs, diagnostic tools, industrial materials, new plants or animal species, or changing the ways in which agriculture, energy production or other types of industry may be practiced.

Biotechnology firms may be classified by the main market orientation they have. One commonly used classification system - the one used here - classifies firms into five groups by their market focus: therapeutics, diagnostics, agritech, suppliers, and others. *Therapeutics* firms are those firms pursuing products intended to cure or reduce the incidence of disease, and, therefore, their products normally require extensive clinical testing for human or animal use. *Diagnostics* firms are those which develop or design products for a variety of tests for determining the presence of various health or disease states. *Agritech* firms produce a large set of products for application in animal agriculture, veterinary activities, the food/brewing industry, or for various environmental uses. *Suppliers* are those firms that produce specialized inputs for use in bioscience or biotechnology, such as biotechnology reagents, specialized biotechnology software or technical instruments for gene splicing. Some firms have been classified as *"other"* because they pursue some other type of application or because they deal with so many interrelated areas that they are difficult to classify.

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31 Some useful introductions to the science, technology and industrial context of this field include: "Biotechnology", Special Survey published in *The Economist* (April 30, 1988); S. Olsen, *Biotechnology: An Industry Comes of Age* (Washington, D.C.: National Academy Press, 1986); M. A. Levin, et al., *Applied Genetic Engineering: Future Trends and Problems* (Park Ridge, N.J.: Noyes Publications, 1983); J. L. Glick, "The Industrial Impact of the Biological Revolution", *Technology in Society*, 4 (1982), 283-293; S. Prentis, *Biotechnology: A New Industrial Revolution* (New York: George Brazillier, 1984); J. Elkington, *The Gene Factory: Inside the Genetic and Biotechnology Business Revolution* (New York: Carrol and Graff Publishers, 1985).

32 W. F. Woodman, M.C. Shelley II and B.J. Reichel, *Biotechnology and the Research Enterprise: A Guide to the Literature* (Ames: Iowa State University Press, 1989).

33 P. Daly, *The Biotechnology Business: A Strategic Analysis* (London: Frances Pinter, 1985).

Biotechnology is an important new field of technology, from the point of view of this study, for a number of reasons. Worldwide, policy makers and scholars see biotechnology as a core technology in the new long wave of economic activity which many observers suggest the international economy is now entering.[34] California is especially important here because it is the place where biotechnology emerged from the scientists' laboratories and first took on a commercial form. This edge has been maintained, furthermore, with most observers acknowledging the state's biotechnology industry to still be the international leader, despite the threat of competition from elsewhere.[35] The California biotechnology industry is also something of a harbinger for the United States, presently accounting for about one quarter of all the biotechnology firms in the country. The next most significant states, from the perspective of firm populations, are New Jersey (10.5% of the U.S. biotechnology firms - and home to many of the major chemical and pharmaceutical corporations), New York (8.6%), and Massachusetts (8.0%).[36] The percentage of U.S. biotechnology companies based in California has declined from almost 30% at the beginning of the decade to its present level, reflecting the fact that many other states have now entered the industry, building up the competitive stakes. In absolute terms, however, California has in some respects increased its lead: at the beginning of the 1970s the number of biotechnology firms in California was only three higher than the number in each of the next most populous states (New Jersey and New York), and four higher than in Massachusetts, but by 1987 the gap had increased to 71 above New Jersey, 91 above New York, and 94 above Massachusetts.[37] The California biotechnology industry is also more substantial than its interstate counterparts in a number of respects: its firms average higher revenues, higher assets, higher shareholder's equity levels, and higher levels of investment in intellectual property and research than those U.S. biotechnology firms outside the state.[38] In short, the California biotechnology industry is the oldest, largest and most highly observed of the world's regional biotechnology "industries", and is therefore an obvious one on which to conduct a case study.

The California biotechnology industry is also of theoretical interest because California is also the home of Silicon Valley, and plays a similar leadership role in microelectronics innovation

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[34] See. e.g., The Commission of the European Communities, *Eurofutures: The Challenges of Innovation*, FAST report (London: Butterworths, 1984).

[35] E. J. Blakely, *The Economic Development Potentials of California's Biotech Industry*, Working Paper #498, Institute of Urban and Regional Development, University of California at Berkeley, April 1989; cf., A. Yoshikawa, *The Japanese Challenge in Biotechnology: Industrial Policy*, Working Paper #29, Berkeley Roundtable on the International Economy, University of Califiornia at Berkeley, September 1987.

[36] P. Hall, L. Bornstein, R. Grier and M. Webber, *Biotechnology: The Next Industrial Frontier*, Working Paper #474, Institute of Urban and Regional Development, University of California at Berkeley, February 1988.

[37] *Ibid.*, p. 14.

[38] K. W. Willoughby and E. J. Blakely, *Making Money from Microbes: Finance and the California Biotechnology Industry*, Working Paper #89-166, Center for Real Estate and Urban Economics, Institute of Business and Economic Research, University of California at Berkeley, August 1989.

as it does in biotechnology. The state therefore provides a fascinating laboratory for comparative studies of high technology industries. Blakely and Nishikawa make the following pertinent observation:[39]

> Texas, California, Massachusetts, and North Carolina are well known for their aggressive economic development policies focusing on high technology. In fact, it has been the leadership of these states that has stimulated a fierce competition among the rest of the nation's states to enter the high-stakes, high-risk area of developing a high-technology economic base. ... Many state policy makers see the emerging field of biotechnology as the new "golden economic goose" that will provide them with the technological capacity to compete with California and the other leading states for technology leadership and industrial wealth.

The data on the California biotechnology industry reported in the balance of this paper are drawn from a telephone survey of the chief executive officers of the state's biotechnology firms, conducted by the Biotechnology Industry Research Group (BIRG) of the University of California at Berkeley, during the spring of 1988.[40]

4. Basic Geography of the Industry

According to BIRG's survey there were 114 *bona fide* biotechnology firms operating in California early in 1988, together employing an estimated total of over 17,000 people.[41] The average employment level of California firms was 152 people, against an estimated national average of 202 people/firm.[42] Despite competition emerging from other states and countries, and despite a stringent financial environment in recent times, the scale of the industry appears to be be continually increasing, measured by the number of firms, the employment level, or by financial parameters.[43]

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39 Blakely and Nishikawa, *The Search, op cit.*, p. 1.

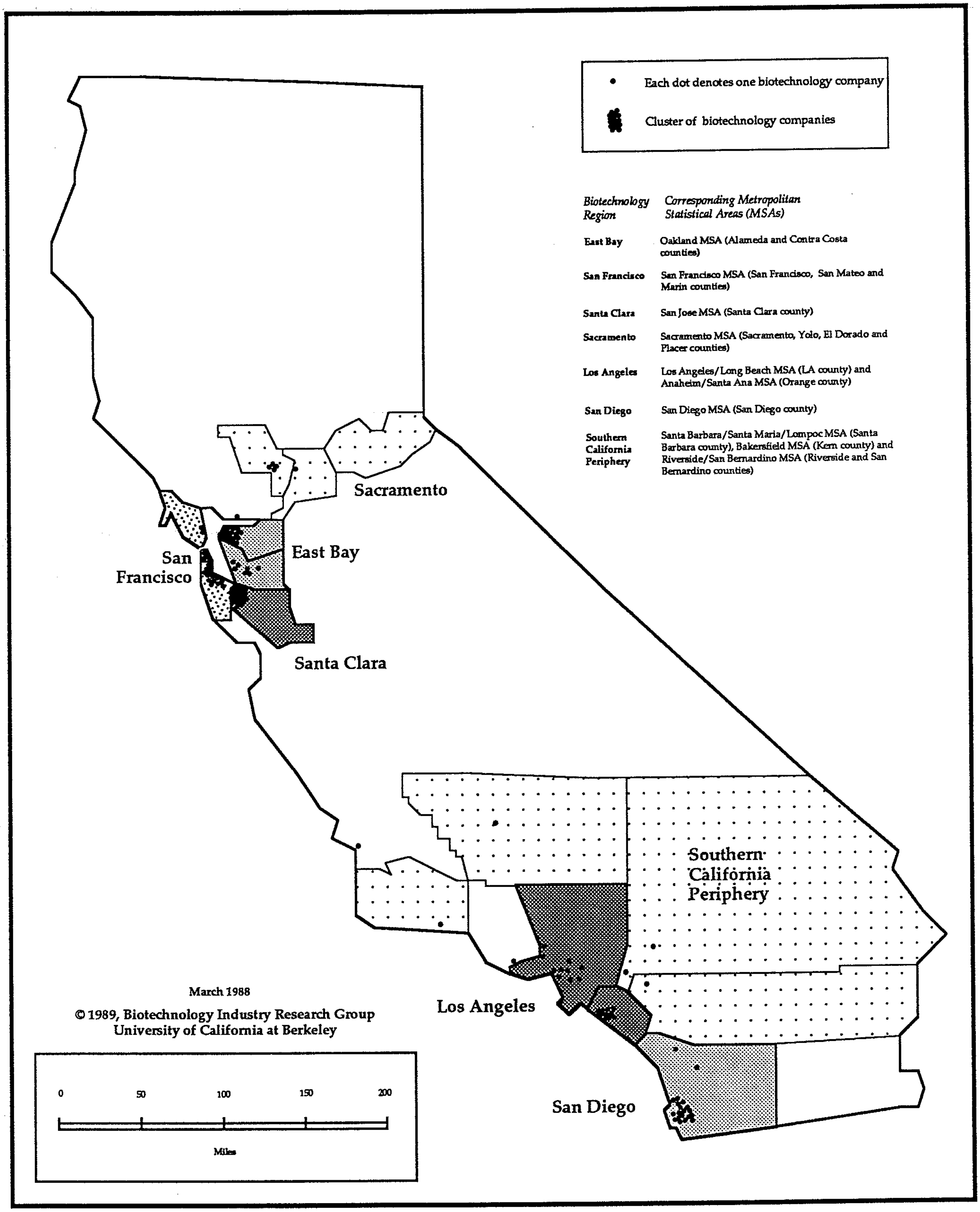
40 The survey instrument was administered for BIRG by the Survey Research Center of the University of California at Berkeley, and involved a 20 minute telephone interview of C.E.O.s by trained professional interviewers. The population of firms was identified by BIRG from a variety of data bases and published 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%). 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.

41 The actual total number employed by the California biotechnology industry (business establishments only) during March 1988 was estimated by BIRG to be 17,326.

42 The national mean of 202 people/firm was estimated by the Arthur Young High Technology Group (*Biotech 88: Into the Marketplace* [San Francisco: Arthur Young, 1987]).

43 Willoughby and Blakely, *Making Money from Microbes, op cit.*

Map A *California Biotechnology Industry Regions*



To examine the spatial aspects of the industry each of the firms identified in BIRG's survey were mapped (see Map A). Each of the 114 biotechnology establishments is denoted by a dot. As shown in Map A the firms are largely located in the two great metropolitan mega-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 mega-regions.

A definite pattern is apparent with the firms clustering in a number of urban regions within these mega-regions: "Silicon Valley" in Santa Clara county, Upper Peninsula/San Francisco, Berkeley/Emeryville/Oakland (the East Bay), San Diego, and the combined city of Los Angeles/Orange. There are also a few smaller concentrations - in Alameda County, between Palo Alto and Berkeley, and the Davis-Sacramento area. The firms are clustered fairly tightly in Orange County, but more loosely in Los Angeles County, but in both cases in the general vicinity of the University of California campuses (U.C. Irvine and U.C.L.A.). The lower density clustering in Los Angeles may be a reflection of the very high land values around the U.C.L.A. campus (contiguous with Beverly Hills), but is probably also a reflection of the general land-use patterns in the L.A. metropolis (Los Angeles and Orange). Each of these urban regions are, among other things, also the locations for major university centers in the bio-medical sciences; and, roughly speaking, they are regions which are also quite well identified for their role as locations for other high technology industries.

The shaded areas in Map A represent the regions around each of the urban biotechnology clusters. The size of the regions is not meant to reflect the relative size of the biotechnology industry in each location; rather, the boundaries correspond to the official boundaries of the Metropolitan Statistical Areas (MSAs) within which the clusters occur. The seven "biotechnology regions" are labeled: East Bay, San Francisco, Santa Clara, Los Angeles, San Diego, Sacramento, and Southern California Periphery. The *East Bay* consists of the Oakland MSA; *San Francisco* consists of the San Francisco MSA; *Santa Clara* consists of the San Jose MSA; *Los Angeles* consists of the Los Angeles/Long Beach MSA and the Anaheim/Santa Ana MSA combined; *San Diego* consists of San Diego MSA; and, *Sacramento* consists of the Sacramento MSA. *Southern California Periphery* refers the periphery of the greater Los Angeles region; it is problematic because it does not actually have an urban cluster of biotechnology firms, and the sample size is low; but it is important to recognize the fact that such firms exist. Firms from this region included in BIRG's data set are located in Bakersfield MSA, Santa Barbara/Santa Maria/Lompoc MSA, and Riverside/San Bernardino MSA. The regions are defined to include only the firms represented in BIRG's survey sample (seventy two), but Map A shows that these are representative of the whole population of firms. The regions contain 81% of the total human population of California.

5. Regional Variations in Biotechnology Firms and Jobs

Northern California contains about 57% of the firms (65 firms) and about 56% of the employment (9,754 people), while Southern California contains about 43% of the firms (49 firms) and about 44% of the employment (7,572 people). Thus the mean size of firms is similar in both Northern California (150 people/firm) and Southern California (155 people/firm). A more complex picture emerges if individual regions are examined.

The largest mean firm size (299 people/firm) occurs amongst the firms in the Southern California Periphery region. The number of Southern Periphery firms in the sample (three) is too small to form the basis of reliable generalizations; but, the figures provide tentative evidence that those firms which locate in non-dominant regions, away from major biomedical research universities, tend to be reasonably substantial. This stands to reason, as smaller start-up firms are more likely to depend upon close proximity to universities and sources of expertise and information than are the larger firms which may already have built up equivalent resources in-house, or have reached a plateau in product development which enables manufacture in a less central location. The major metropolitan locations contain both very large and very small firms, with the latter bringing down the mean firm size to less than that of the non-metropolitan firms.

Firms in the East Bay (167 people/firm) average about the same size as Los Angeles firms (166 people/firm), and are larger than those in the San Diego (120 people/firm), San Francisco (107 people/firm) and Sacramento (67 people/firm) regions. The metropolitan region with the largest mean biotechnology firm size is Santa Clara (187 people/firm).

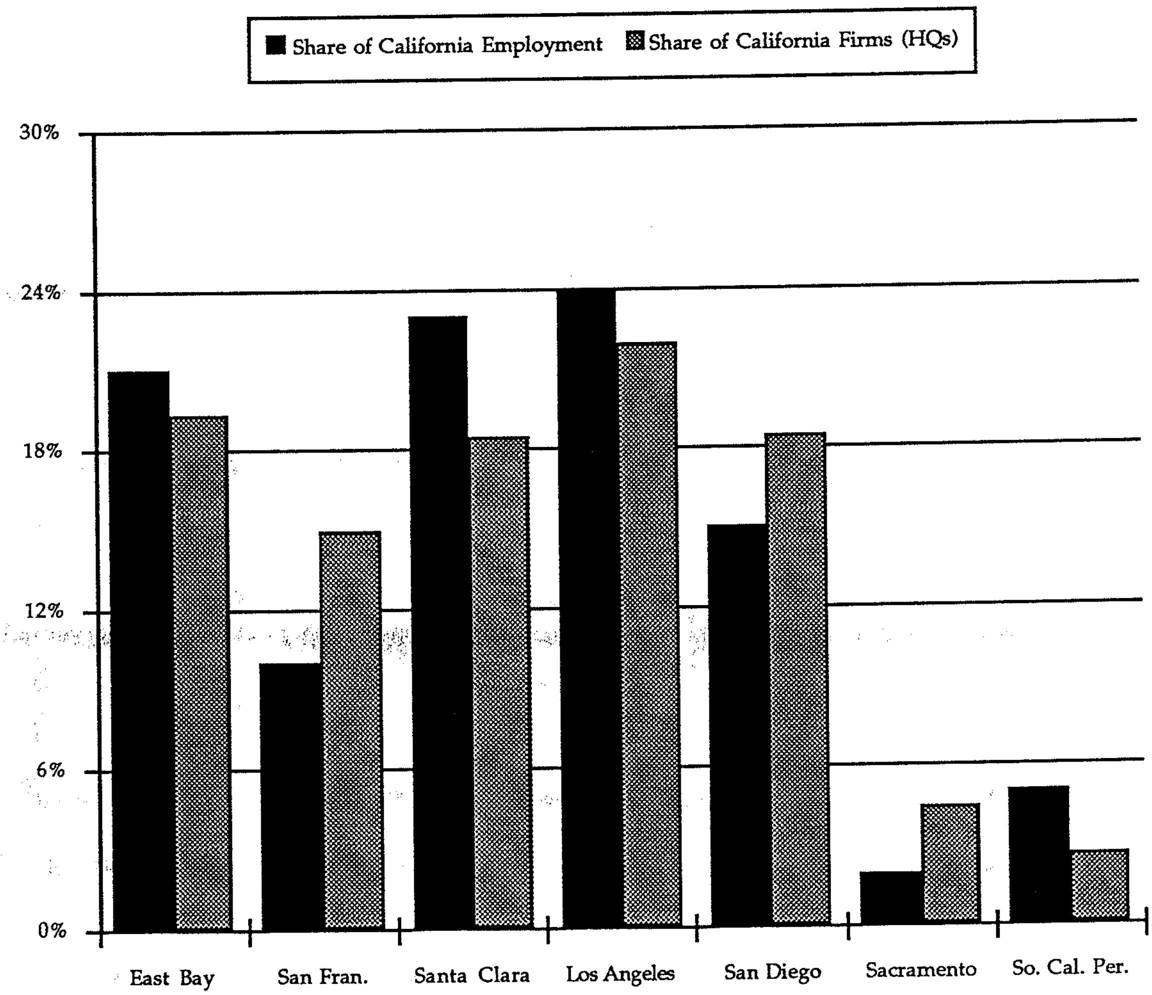
Table One
Regional Employment and Firm Populations
(all businesses, high technology, biotechnology), California

March, 1988	East Bay	San Fran.	S. Clara	Los Ang.	S. Diego	Sacram.	S. Ca. Per.	California
Business employment	673,300	800,900	730,100	4,605,300	746,200	394,900	796,000	10,283,700
Hitech employment	43,425	18,664	218,217	508,980	73,399	13,445	41,738	968,866
Biotech employment	3,667	1,816	3,935	4,150	2,524	336	898	17,326
Business establishments	46,000	54,403	34,081	274,580	49,272	30,719	56,914	709,341
Hitech establishments	709	440	1,448	5,370	739	203	645	10,661
Biotech establishments	22	17	21	25	21	5	3	114

Source: BIRG survey (biotech data); California Employment Development Department, ES-202 Program, (all other data).

Chart One

California biotechnology industry, regional distribution of firms and jobs, 1988



Source: BIRG, 1988.

Chart 1, based upon data in Table 1, shows that the region which makes the state's single largest direct contribution to biotechnology employment is Los Angeles.[44] This region, which is responsible for 24% of the industry's total employment, is followed closely by Santa Clara (23%) and the East Bay (21%). Los Angeles also contains the the largest proportion of the state's firms (22%), followed closely by the East Bay (19%), and then by Santa Clara and San Diego together at 18% each. The relative contributions of each region to employment and firm populations suggest that there is a greater preponderance of firms in the start-up stage in the San Diego, San Francisco

[44] For data sources and related definitions of items in Table 1, see Appendix 1.

and Sacramento regions than in the Los Angeles, East Bay and Santa Clara Regions; firms in the latter regions appear, on average, to be relatively more developed.

The above information may be summarized by the following observation.

Observation #1. The California biotechnology industry is neither homogeneous nor randomly distributed, but clustered in distinct geographical (urban) nodes.

6. The Relative Productivity of Regions as Incubators of Biotechnology Industry

The figures displayed in Chart 1 represent the absolute employment and firm levels in each region but do not relate this information to the relative size and scope of each regional economy. Chart 2 addresses this problem by plotting two measures of the *density* of the California biotechnology industry in each region.[45] In this way the industry figures for each region are standardized to enable more legitimate industry performance comparisons across regions. The biotechnology location quotient (LQ) expresses the level of industrial biotechnology employment in each region against total state industrial biotechnology employment, total business employment in each region and the total business employment for the whole state. The biotechnology firm density index (FDI) expresses the population of biotechnology firms in each region against the total state population of industrial biotechnology firms, the number of business establishments of all types in each region and total number of business establishments for the whole of California.

Chart 2 shows that, taking into account the state-of-the-industry throughout California (i.e., the biotechnology industry) and the extent of the base economy in each region, the East Bay emerges as the region with the highest density from the perspective of biotechnology *employment* (followed very closely by Santa Clara). In this sense the East Bay may be viewed as the most "productive" biotechnology region. Similarly, from the perspective of industrial biotechnology *firms*, Santa Clara emerges as the most "productive" (i.e., it has the highest "density" of biotechnology firms). San Diego emerges as the third most "productive" biotechnology industry region, for both employment and firm levels. The most notable result, however, is that while the Los Angeles region is clearly the most significant contributor to biotechnology employment and firms levels, in absolute numbers, it is by far the least "productive" region when its biotechnology industry is standardized against the base economy for comparison with the other regions.

Observation #2. The absolute size of a biotechnology industry in an urban region does not appear to be a good indicator of the "productivity" of that region as an incubator of a biotechnology industry.

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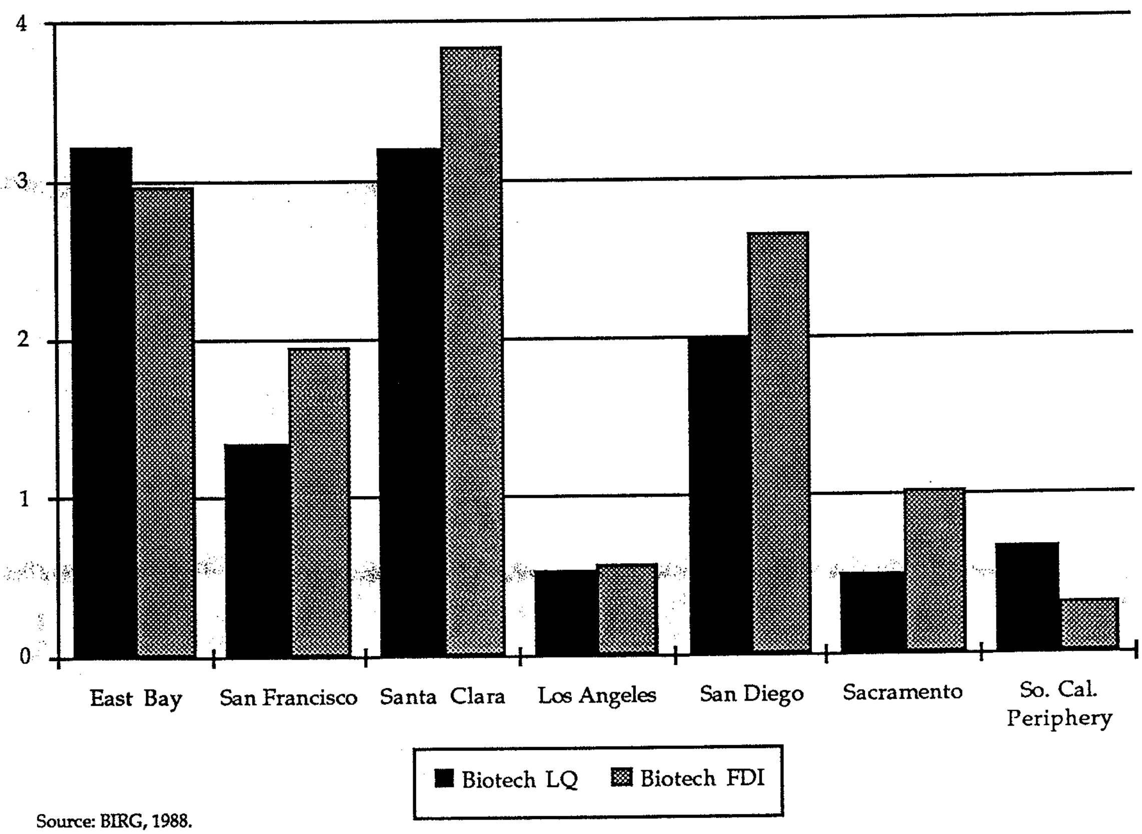
[45] For data sources and definitions relevant to this and the following industry density measures, see Appendix 1.

Chart Two

Biotechnology Location Quotients and Firm Density Indices
California Regions, 1988



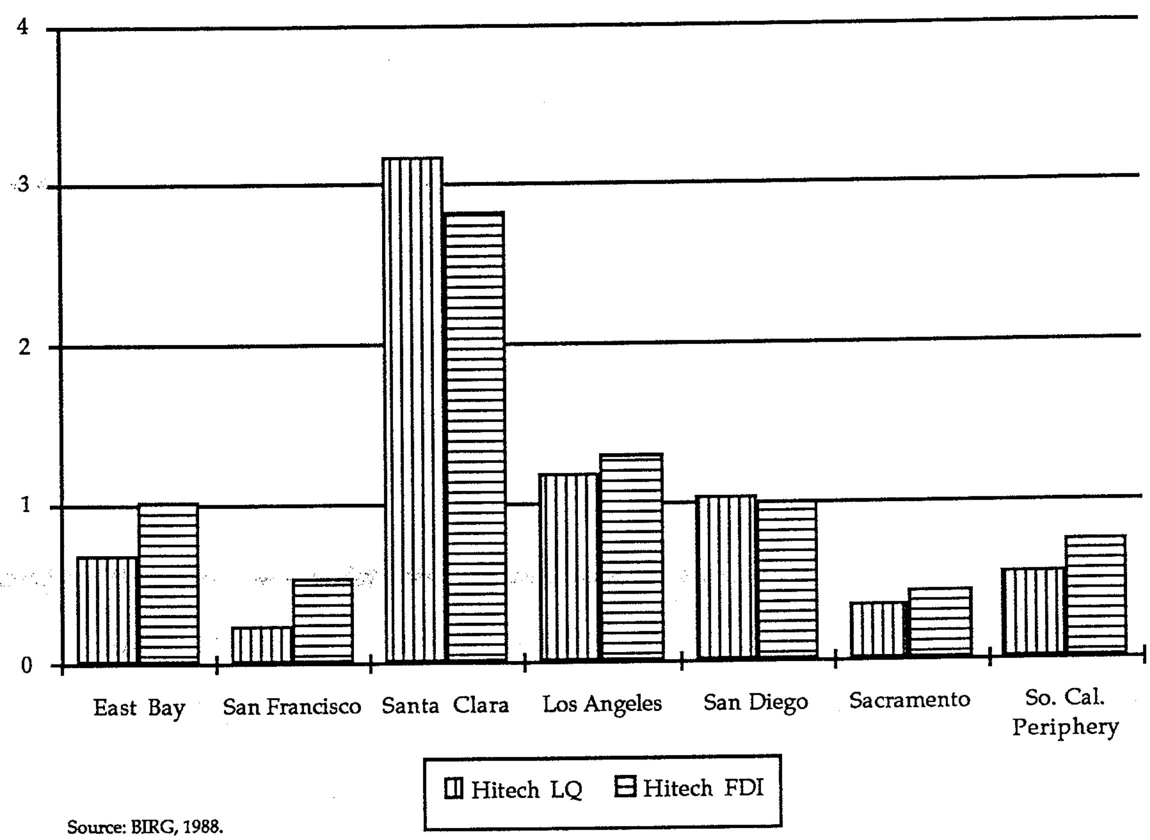
Source: BIRG, 1988.

7. "High Technology" Competitiveness and Biotechnology Competitiveness

Having now provided a basic profile of the dimensions and relative strength of California's biotechnology regions we are now in a position to examine one of the core questions raised at the beginning of this paper: will the regional form of one advanced technology industry necessarily be duplicated in another advanced technology industry? At first glance, the fact that California has played a leadership role in both of the two recent "high technology" industry forms, micro-electronics ("informatics") and biotechnology, and that the biotechnology regions have emerged in roughly the same geographical areas within California as the micro-electronics regions, suggests "yes" as an answer. On closer examination, however, the picture becomes more complicated.

Chart Three

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



Source: BIRG, 1988.

Chart 3 compares each of California's biotechnology regions by the relative strength of the overall high technology economy in each region. "High technology" is used here with the precise meaning given to it by Markusen, Hall and Glasmeier, based on the notion that "high" denotes high technical capacity in the workforce of an industry.[46] The high technology location quotient (Hitech LQ) and high technology firm density index (Hitech FDI) measure the density of high technology industry in each region against the backdrop of the industrial economy in general.

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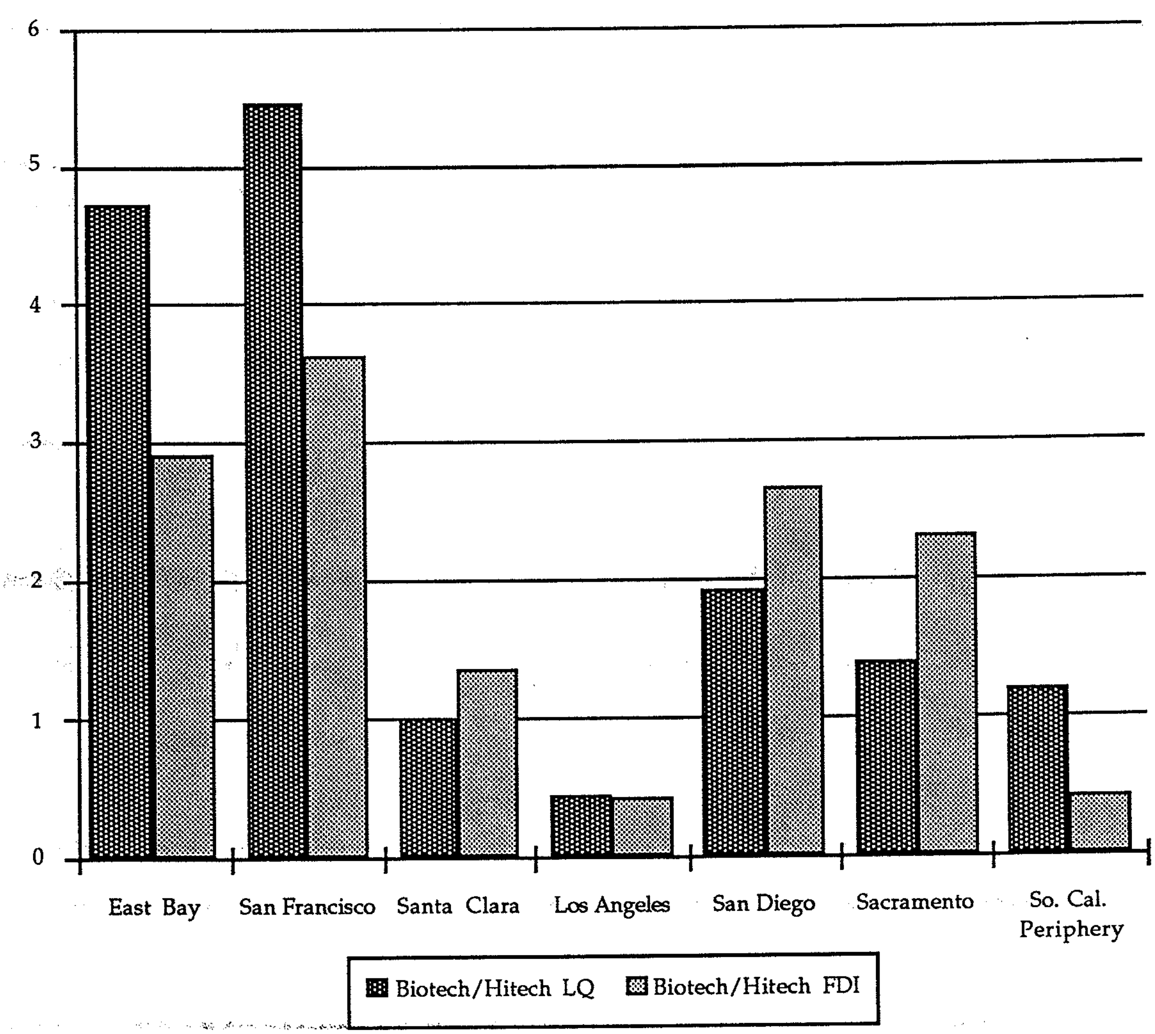
46 See Appendix 1.

As would be expected, in view of the outstanding place of Silicon Valley as a high technology region, Santa Clara has the largest Hitech LQ and FDI by a big margin. Santa Clara's Hitech LQ is almost five times that of the East Bay (whereas its Biotech LQ was actually slightly smaller). This suggests that there is a very weak link, if any, between the "productivity" of a region as an incubator of high technology in general, on one hand, and biotechnology in particular, on the other hand. This conclusion is confirmed by the fact that, after Santa Clara, Los Angeles is

Chart Four

Biotech/Hitech Location Quotients and Firm Density Indices
California Regions, 1988



Source: BIRG, 1988.

the most productive high technology industry region (by these measures), despite having a huge "non-hitech" sector of its economy which one might have expected to dilute the high technology component. Chart Four, which plots the regional density of biotechnology firms and employment against the background high technology industry base, reinforces the conclusion even more vividly.

While there has been some tendency for biotechnology firms to cluster in regions known for their high technology industry, it does not follow that regions which are presently high technology leaders will necessarily also be the strongest regions in biotechnology. Biotechnology industry appears to thrive upon a special set of factors not necessarily required by other high technology industries.

Observation #3. The relative capacity of a region to produce a biotechnology industry is not proportional to its relative competitiveness in high technology industry in general.

8. Regional Variations in the Industrial Character of Biotechnology

The above observations led us to search for explanations for the regional clustering of biotechnology firms and the variation between regions in the density of the biotechnology industry. Given that regional variations in the existing high technology base do not appear to provide an adequate explanation, we examined California's biotechnology regions for the industrial character of the biotechnology clusters in each of them. We did this by categorizing each region according to the primary and secondary market orientations of its biotechnology firms. The results are documented in Table Two.

More than one in three biotechnology firms in California (35%) concentrate their activities around the market for diagnostic products, with about one quarter more (24%) concentrating on the therapeutics products market. This state-wide pattern (diagnostics as primary orientation and therapeutics as secondary orientation) is reproduced in the San Francisco and the San Diego regions (with the latter having a relatively strong emphasis on therapeutics), but each of the other regions exhibits a peculiar mixture in the market orientation of firms. The East Bay stands out as the only region with its strongest market orientation being towards therapeutics applications of biotechnology. Both of the non-metropolitan biotechnology regions are distinguished by having agritech as their primary market focus; although they differ in their secondary focus. Of particular interest is Santa Clara which has the strongest specialization of any of the regions, with 80% of its biotechnology firms exhibiting a single primary market focus. The preponderance of suppliers in the Santa Clara region suggests that, unlike the overall pattern with other regions, the existing high technology base of the region ("Silicon Valley") has exerted some influence on the character of its biotechnology firms. Furthermore, this specialization suggests that a symbiotic relationship exists between the biotechnology firms in Santa Clara and those elsewhere in the Bay Area, with the latter providing the market for the products of the former.

Table Two
Market orientations of California biotechnology firms by geographical region, 1988

Region	Primary market orientation (% of region's firms) (region's share of all firms with this market orientation)			Secondary market orientation (% of region's firms) (region's share of all firms with this market orientation)		
East Bay	therapeutics	40 %	*35%*	diagnostics	33 %	*20%*
San Francisco	diagnostics	29 %	*20%*	therapeutics	24 %	*24%*
Santa Clara	suppliers	80 %	*29%*	diagnostics	20 %	*4%*
Los Angeles	diagnostics	53 %	*32%*	suppliers	20 %	*21%*
San Diego	diagnostics	33 %	*16%*	therapeutics	33 %	*24%*
Sacramento	agritech	40 %	*17%*	suppliers	20 %	*7%*
So. Cal. Periphery	agritech	67 %	*17%*	diagnostics	33 %	*1%*
California	diagnostics	35 %	*100%*	therapeutics	24 %	*100%*

Source: BIRG, 1988.

Observation #4. There are substantial variations in the character of the biotechnology industry between regions as reflected in the market orientation of the biotechnology applications pursued by firms.

This observation raises the question of why regional specialization of biotechnology firms may be observed in California.

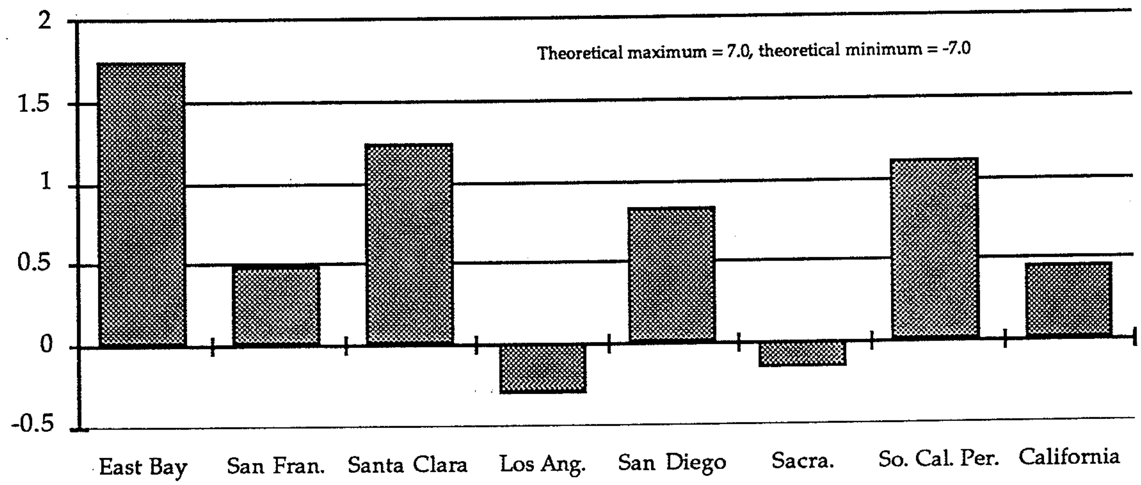
9. Regional Context as a Determinant of Industrial Variety in Biotechnology

In our survey of California's biotechnology firms we asked CEOs a number of questions about the factors which affected whether or not California was an advantageous place for biotechnology manufacturing. Their responses to these questions can provide clues to help us answer the above question about the regional specialization of biotechnology firms. With this in mind we constructed a "locational advantage index" for the firms in each region of the state (see

Chart Five). This index provides an indication of differences between regions in managers' perceptions of how advantageous it is, overall, to be based in California for biotechnology manufacturing. The index takes into account such factors as: the availability of raw materials; proximity to markets; the cost of industrial space; the availability of existing manufacturing facilities; the regulatory environment; the proximity to a firms R&D facilities; and other factors.

Chart Five

Locational advantage index of California for biotechnology manufacturing



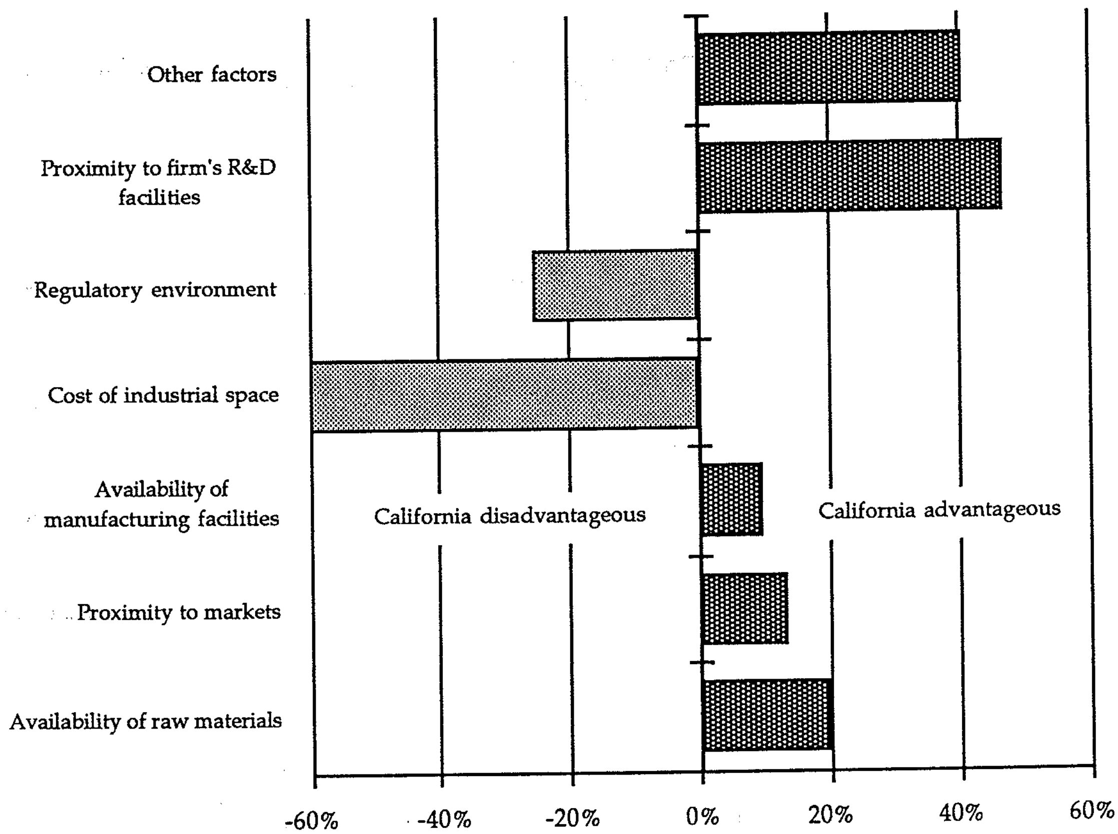
The index is the sum of seven locational advantage scores for each region, where each score is the proportion of firms in the respective region which consider the respective locational factor to make manufacture in California advantageous.
A negative score for a factor would mean that the majority of firms considered that factor to make being located in California a disadvantage for manufacturing.
The seven locational factors are: availability of raw materials; proximity to markets; cost of industrial space; availability of existing manufacturing facilities; regulatory environment; proximity to firm's R&D facilities; other factors.

Source: BIRG, 1988.

Chart Five shows that, on the whole, California biotechnology firms do find being located in California to be an advantage for manufacturing. This is an interesting observation in view of the relatively high costs of industrial land in the state. Chart Five also reveals notable variations in the index for the industry clusters in each region; this suggests that there are real variations in the conditions relevant to manufacturing in each of the regions. The three strongest (i.e., most "productive") biotechnology industry regions identified in Chart Two (East Bay, Santa Clara, and San Diego) turn out also to register high scores on the locational advantage index. Hence, it appears that there is a connection between the conditions which prevail within each region and the prominence of the local biotechnology industry. Once stated, this conclusion sounds rather like common sense; but it is important to recognize that our data present evidence that the dynamics of the biotechnology industry cannot be understood simply as an outgrowth of factors internal to either firms or the industry level of analysis. The regional context influences firm-level and industry-level dynamics.

Chart Six

Factors affecting the relative attractiveness of California for biotechnology manufacturing, 1988



Percentage of biotechnology firms which consider each factor to make location in California advantageous for manufacturing

Source: BIRG, 1988.

Chart Six shows the range of factors incorporated in the locational advantage index, aggregated for the whole California biotechnology industry. It reveals that the single most attractive feature about California as a biotechnology manufacturing location is the fact that the firms' research-and-development facilities are already located there, suggesting that whatever factors make a location attractive for research-and-development indirectly also make it attractive for manufacturing. Chart Six also shows that there are some disadvantages to manufacturing in the same regions that are attractive for research-and-development - high costs for industrial space, and a seemingly inhospitable regulatory environment - but that a range of other salient factors counterbalance these disadvantages. Chart Five suggests, furthermore, that the magnitude and combination of the advantages and disadvantages of each region vary considerably. Given that there are contrasts in the general character of biotechnology firms between regions, it follows that different market clusters of biotechnology firms require correspondingly different environments, and that the different regional environments, in turn, tend to produce different types of industry clusters.

Observation #5. Regions themselves are the incubators of biotechnology industry complexes, thereby accounting for regional variations in the character of firms; and the attractiveness of the regional context for biotechnology industry varies considerably between regional clusters of firms.

10. Factors Determining Location Decisions of Biotechnology Firms

The connections between the industrial character of a regional cluster of biotechnology firms and the corresponding conditions of the region can be further explored by examining the factors which firms' consider to be important determinants of their location decisions for both research-and-development facilities and manufacturing facilities. Tables Three and Four report the results on this subject from our interviews of the managers of biotechnology firms in each of California's seven regional clusters.

Table Three reveals that, across the whole state, the availability of qualified labor and proximity to major research universities are the two factors which most influence decisions over the location of biotechnology *research-and-development* facilities. Cost-related factors (such as the price of industrial space, or wage rates) do feature prominently here, but are quite subsidiary to the prime determinants, which are concerned with access to people and knowledge. Cost factors (represented by concern about the cost of industrial space) do appear, however, as shown by Table Four, to be the prime consideration of firms in their deliberations about the location of their *manufacturing* facilities. Nevertheless, proximity to the firm's research-and-development facility is on average the next most important location-decision determinant, and given the lower concern about cost factors in decisions about R&D location, it follows that there is a tension between cost-related and people-and-knowledge-related factors in the location of biotechnology manufacturing facilities in California.

Tables Three and Four both reveal regional variety in the combination of factors which managers report as being significant determinants of their location decisions, thus reinforcing our earlier conclusion that there is a connection between the character of regions and the character of biotechnology industry clusters. Firms in the two strongest biotechnology industry clusters, East Bay and Santa Clara (see Chart Two), place above average emphasis on the importance locating their manufacturing facilities close to their R&D facilities; and firms in the East Bay (the region with the highest biotechnology location quotient) also places above average emphasis on the importance of costs factors in the location of manufacturing. In the case of R&D facilities, furthermore, both the East Bay and Santa Clara place above average emphasis on the importance of the top location-decision determinant (access to appropriate people) *and* on the importance of cost-

Table Three

Determinants of location decisions for R&D facilities among California biotechnology firms in different geographical regions, 1988

Factor (ranked by importance)	*% of firms in each region which consider each factor to be an important determinant of location decisions*							
	East Bay	San Fran.	Santa Clara	Los Angeles	San Diego	Sacra-mento	So.Cal. Periph.	Whole State
Availability of qualified labor	93%	88%	100%	87%	83%	100%	67%	89%
Proximity of research univs.	87%	94%	80%	67%	92%	100%	100%	86%
Cost of industrial space	87%	69%	100%	67%	58%	60%	67%	72%
Wage rates	60%	69%	80%	53%	42%	60%	33%	58%
County & city regulations	73%	56%	60%	47%	42%	40%	0%	52%
Local taxes	53%	44%	40%	33%	33%	40%	0%	40%
State taxes	60%	50%	40%	33%	17%	40%	0%	40%
Proximity of suppliers	13%	31%	80%	33%	25%	40%	33%	31%
Proximity to sources of finance	33%	38%	40%	13%	0%	20%	0%	23%

Source: BIRG, 1988.

related factors (this is especially so for the East Bay). The fact that Santa Clara is primarily a region of biotechnology suppliers, and that the East Bay (adjacent to Santa Clara) is the premier "end product" biotechnology region in California, suggests that there is likely to be some dependency between the locational determinants of the firms in each of the two regions.

Table Four

Determinants of location decisions for manufacturing facilities among California biotechnology firms in different geographical regions, 1988

Factor (ranked by importance)	*% of firms in each region which have considered each factor in location decisions*							
	East Bay	San Fran.	Santa Clara	Los Angeles	San Diego	Sacra-mento	So.Cal. Periph.	Whole State
Cost of industrial space	87%	82%	80%	79%	67%	80%	100%	80%
Proximity to firm's R&D facility	80%	77%	80%	57%	58%	80%	67%	70%
Regulatory environment	73%	44%	60%	79%	50%	80%	100%	64%
Access to pre-existing ind. space	47%	53%	40%	86%	67%	60%	67%	61%
Proximity to markets	40%	35%	40%	36%	58%	60%	67%	44%
Availability of raw materials	40%	24%	0%	43%	25%	20%	0%	28%
Competition with pharm. co's.	13%	12%	0%	14%	8%	20%	33%	13%
Distance from Fed. reg. agencies	13%	0%	0%	21%	17%	0%	33%	11%
Other factors	27%	41%	40%	14%	58%	20%	0%	32%

Source: BIRG, 1988.

The general conclusion to which the above discussion leads us is that the tension between different determinants of location decisions will be resolved in a different way by each cluster of firms. The fact that the tension is most pronounced for the industry cluster which appears to be generally the most rooted in the special people-and-knowledge resources of its region (the East Bay), and therefore the least free to seriously entertain the prospects of re-locating, raises the likelihood that pre-existing conditions which led to the incubation of the industry cluster in the first place may be more influential determinants of "downstream" location patterns than are the subsequent deliberations of the managers of biotechnology firms.

Observation #6. Biotechnology firms vary between regions in the factors which they consider to be important as determinants of their location decisions.

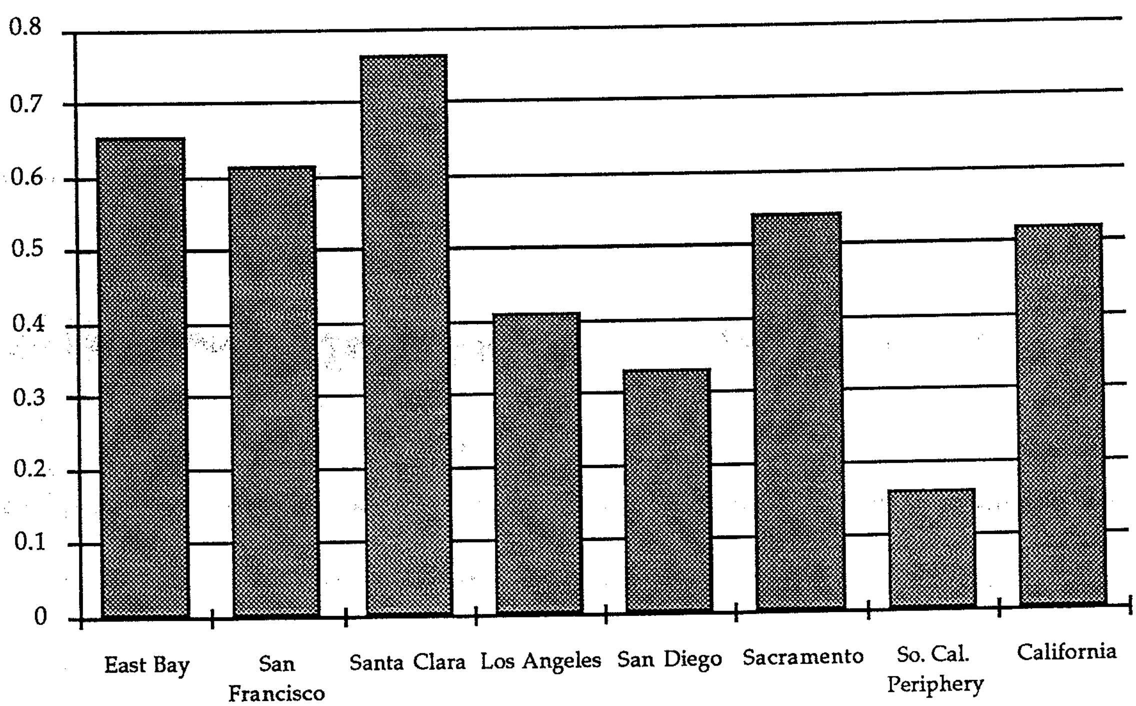
11. The Importance of "Location" for Biotechnology Firms

Taken together, the preceding six summary observations create a picture of the California biotechnology industry in which there is a dynamic relationship between the nature of each biotechnology industry cluster and the nature of the local regions in which they have been incubated. This picture evokes the idea that "location" itself is a strategic variable for the biotechnology industry. To test this we constructed an "index of locational concern" from our data set. This index essentially reflects the degree to which managers of biotechnology firms concern themselves which locational factors in their managerial practice.[47] The results are revealed in Chart Seven.

Chart Seven shows that there are variations in the index of locational concern between each

Chart Seven

Index of locational concern by biotechnology firms



Source: BIRG, 1988.

Theoretical maximum = 1.0

regional biotechnology industry cluster. The main pattern which emerges is that the biotechnology industry regions in Northern California all score above the index of the industry state-wide, while

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[47] The exact formula for calculating the index for each region is as follows. Index-of-locational-concern for region R = (sum$_{\text{factors 1-n}}$[% firms in region R which consider factor to be an important determinant of R&D location decisions])/(100n), where n = the total number of factors considered in the BIRG survey.

all of the biotechnology industry regions in Southern California score below the state-wide index. It is difficult to provide explanations for the size of the index for each individual region, but Chart Seven affirms our earlier supposition that there is regional variety in the locational dynamics of the biotechnology industry. It also extends our analysis by suggesting that the *strength* of the determination of industrial variety in biotechnology by the regional context varies itself from region to region. The fact that the biotechnology industry in Northern California is further developed than that of Southern California, in terms of its total size and as indicated by various "density" measures (see Charts Two and Four), leads us to believe that there may be a connection between regional economic development in biotechnology and the degree to which locational factors play an important role in local biotechnology industry clusters. Our index of locational concern is a relatively blunt measure upon which to base such a theory, but taken together with all the other evidence thus far presented in this paper, it adds considerably to the general plausibility of our arguments.

Observation #7. The extent to which "location" may be viewed as an important strategic variable for biotechnology firms varies between regions and the industrial character of firms.

12. Interorganizational Linkages in Biotechnology

The preceding arguments and observations build a case for the idea that the strength of the biotechnology industry in a region stems not so much from *particular* economic factors such as local taxation levels, wage rates, or land prices, but rather from the nature of the *region itself* - what we might call the "regional biotechnology milieu". Thus, the more rich the regional biotechnology milieu, the more productive the region may become as an incubator of biotechnology firms; and it is important to interpret regional strength in biotechnology industry not just by the number of individual firms present (although this is certainly a legitimate measure), but by the degree to which a strong industry *cluster* (or strong industry clusters) may be observed.

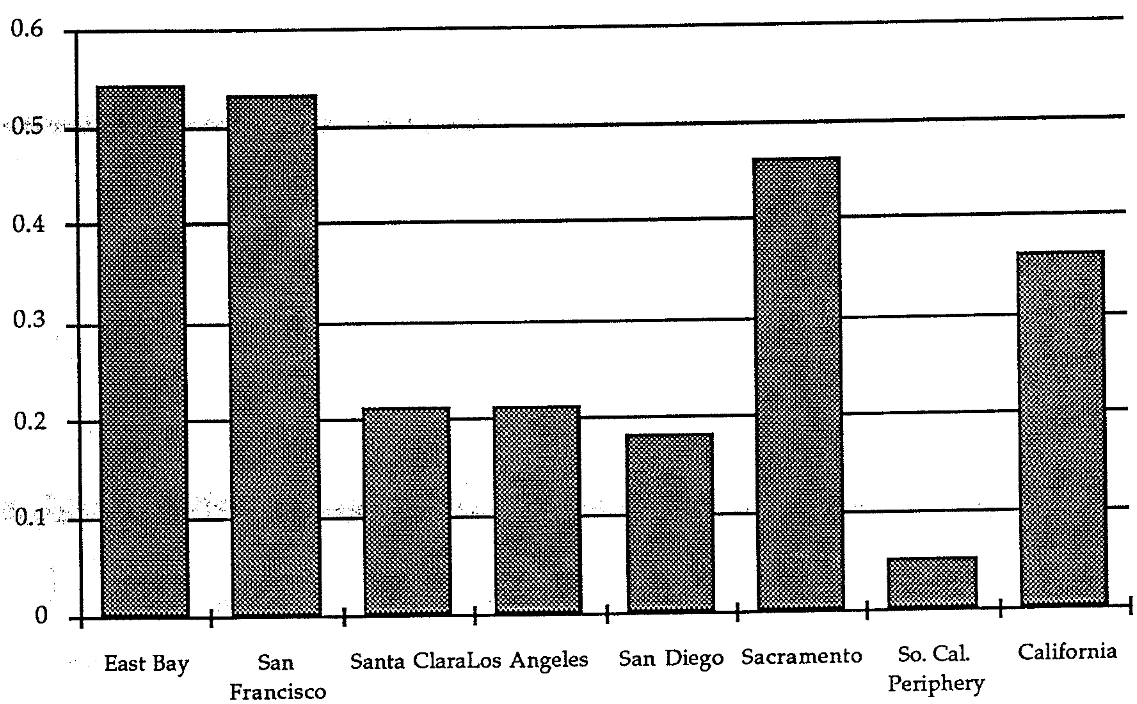
The idea of a regional biotechnology milieu points to the critical role of communication and cooperation between the various actors in biotechnology. The fact that California biotechnology firms cluster in local regions, and that their managers place emphasis on access to people and knowledge as being strategically important, means that interorganizational linkages must be critical to industrial performance.[48] Interorganizational linkages in the biotechnology industry include both linkages to universities or major research institutions, and linkages to other firms. Charts Eight

[48] This theme has also emerged in the work of other scholars studying biotechnology as an industry. See, for example: G. P. Pisano, W. Shan and D. J. Teece, "Joint Ventures and Collaboration in the Biotechnology Industry," in *International Collaborative Ventures in U.S. Manufacturing*, edited by D. C. Mowery (Cambridge, Mass.: Ballinger, 1988); J. Freeman and S. R. Barley, "The Strategic Analysis of Interorganizational Relations in Biotechnology," in *Strategic Management of Technological Innovation*, edited by R. Loveridge and M. Pitt (New York: John Wiley and Sons, 1989).

and Nine plot regional variations in these two different categories of linkages for our sample of California biotechnology firms.

Chart Eight

Index of university collaboration by biotechnology firms



Source: BIRG, 1988.

Theoretical maximum = 1.0

The "index of university collaboration" in Chart Eight is constructed from data collected in our survey of California biotechnology firms on forms of collaboration between firms and universities during the fiscal year leading up to the survey. It covers five general categories of collaboration: licensing technology (other than the Cohen-Boyer patent) from a college or university; contract research performed by a college or university for the firm; subcontract research performed by the firm for a university or college; joint research; or some other type of collaborative relationship.[49] It is an indicator of variations from region to region in the overall level of collaboration (largely formal) between biotechnology firms and universities.

With the exception of the Santa Clara region, a similar conclusion may be drawn about this index as was drawn about the index of locational concern. Firms in Northern California tend to collaborate with universities to a greater extent than do firms in Southern California. The size of the gap, however, is noticeably greater than in the case of the index of locational concern. The fact that Santa Clara biotechnology firms have engaged in collaboration with universities at about the same degree as those in Southern California is probably explained by the special character of the Santa Clara biotechnology industry cluster: its specialization as a supplier region for other biotechnology clusters. This does not necessarily mean that interorganizational linkages are not important for Santa Clara firms, but rather that formal linkages with universities do not appear to be as important in *local* industry dynamics as in other strong biotechnology industry subsectors.[50] The general conclusions we can draw here, however, are that the intensity of linkages with universities vary between biotechnology industry clusters in different regions, and that they are likely to be an important factor explaining regional variations in the "biotechnology milieu".

Chart Nine plots variations between regions in the linkages of California biotechnology firms to other firms, both outside California and outside the United States. Our data set does not cover interfirm linkages within California. The first pattern we note is that the regions containing the firms with the highest incidence of extra-state linkages also exhibit the highest incidence of international linkages. Second, we note that these are the same regions as those which exhibited the highest incidence of collaboration with universities. Third, although the pattern is not perfect, these regions are also the most "productive" biotechnology regions as indicated by data reported earlier in the paper. Fourth, while all the regions exhibit higher incidences of extra-state than international interfirm collaboration, the gap between the two levels of collaboration is less for the regions which are the strongest; it is also interesting to note that the region with the lowest incidence of international collaboration (Los Angeles) is also the region with the lowest "productivity" in incubating biotechnology firms and jobs (see Chart Two). Los Angeles also has the highest percentage of firms which engage in interstate collaboration *without* also engaging in international collaboration (60%, against a state-wide mean of 42%).

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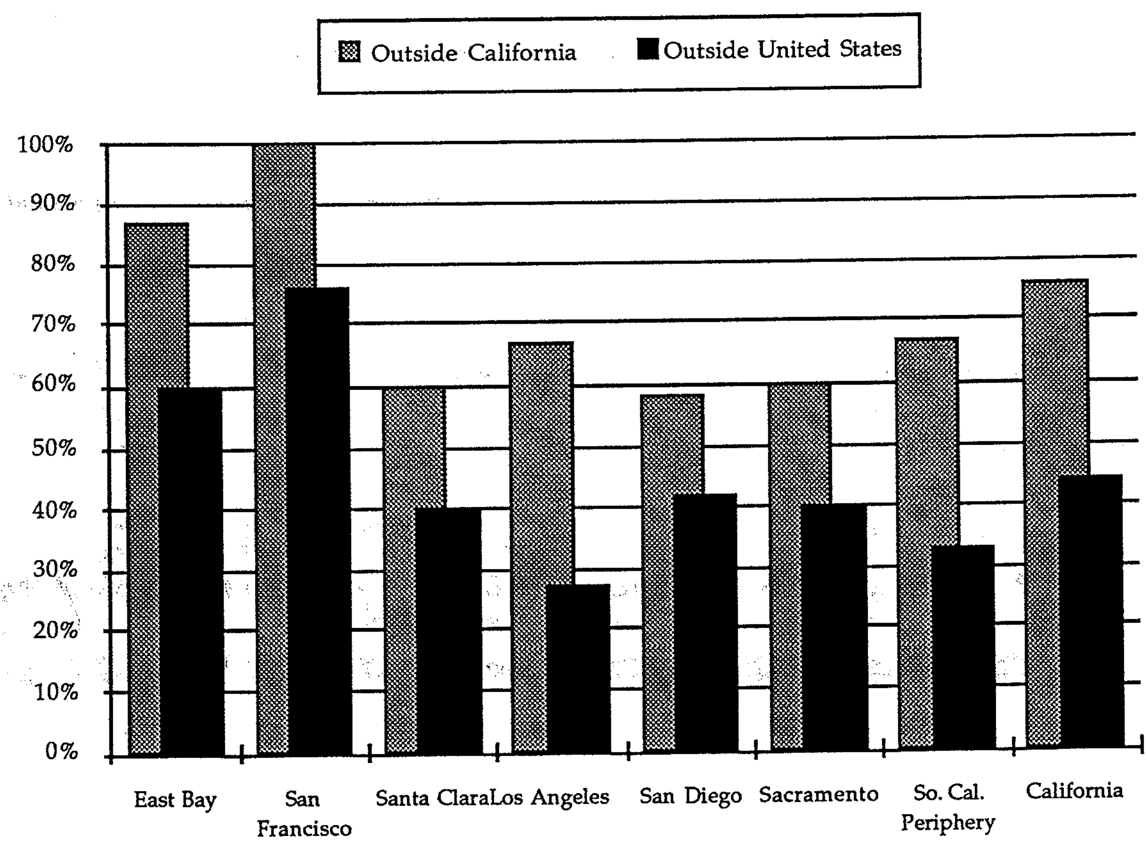
[49] The exact formula for calculating the index for each region is as follows. Index-of-university-collaboration for region R = (sum$_{\text{collaboration categories } 1\text{-}n}$[% firms in region R which have engaged in the respective category of collaboration])/(100n), where n = the total number of categories considered in the BIRG survey.

[50] The extensive research by AnnaLee Saxenian on Silicon Valley has shown that interfirm linkages are both abundant and critical to the rise of Santa Clara as a "high technology" region (A. Saxenian, "Local Area Networks: Industrial Adaptation in Silicon Valley," paper presented at the *Third International Conference on Innovation, Technological Change and Spatial Impacts*, Selwyn College, Cambridge, United Kingdom, September 3-5, 1989.

Being strongly rooted in a local region, drawing heavily upon the assets and environment of that region, does not make it less likely for a biotechnology industry cluster to exhibit a high degree of "connectedness" to organizations outside of the region. The richness of a regional biotechnology milieu appears to be associated simultaneously both with a strong local orientation and a strong "foreign" orientation, and to be nurtured by abundant interorganizational collaboration. This is a reflection of the relative importance of human and knowledge related resources in biotechnology over physical resources.

Chart Nine

Percentage of biotechnology firms which have engaged in joint research with other firms



Source: BIRG, 1988.

Observation #8. Local biotechnology industry clusters appear to be nurtured by forms of interorganizational collaboration, the pattern of which varies from region to region; and the richness of a regional biotechnology milieu is a reflection of the richness of the linkages of the biotechnology firms in the region with relevant organizations both locally and outside the region.

13. A Simple Model for Interpreting Local Economic Development in Biotechnology

On the basis of the empirical evidence presented above, together with the corresponding series of observations, we have developed a rudimentary model for local economic development in biotechnology. The model (Figure One) reflects our discoveries about the regional dynamics of the California biotechnology industry and it also reflects what we see to be the most important issues from the point of view of economic development policy.

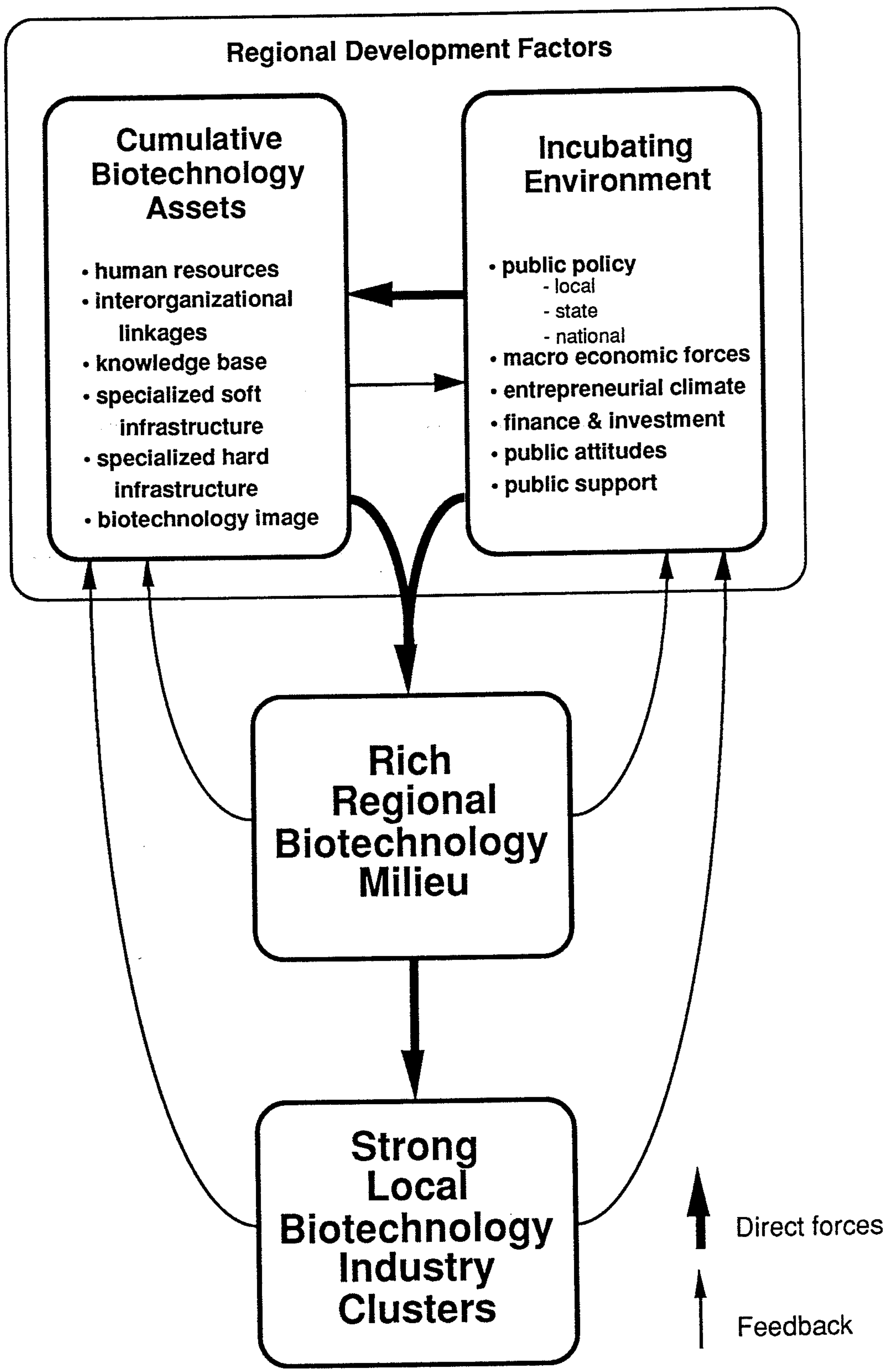
The primary feature of the model is that the regional industrial process associated with biotechnology involves three main dimensions: local biotechnology industry clusters, a regional biotechnology milieu, and regional development factors.

This way of construing the industry builds on our recognition that the biotechnology industry is manifested in local clusters of firms which tend to exhibit similar or related industrial characteristics (e.g., market focus, locational preferences, pattern of linkages, human resource requirements). Locality is a fundamental aspect of the industry's dynamics, not just a theoretically interesting issue for geographers and planners to attach to industry analysis. Economic development in biotechnology is a matter of *local economic development*, and not just of "development" in general.

The model also embodies our insight that local biotechnology industry clusters do not emerge in isolation, but rather within a regional biotechnology milieu. There are two levels at which the concept of "region" is relevant in our study: the *mega-region* (represented by the two major metropolitan conurbations of Northern California and Southern California) and the *local-region* (represented by the seven "biotechnology regions" we have labeled as East Bay, San Francisco, Santa Clara, Sacramento, Los Angeles, San Diego, and Southern California Periphery). Our research indicates that while each of the biotechnology industry clusters is located within a local-region, drawing upon the peculiar features and assets of that local-region in a number of ways, the mega-region in which each of the local-regions is located provides a context in which each of the biotechnology industry clusters has emerged. The concept of the biotechnology milieu applies to both of the regional levels. Local clusters of firms emerge within a local regional biotechnology milieu *and* a mega-regional biotechnology milieu.

Figure One

Model for Local Economic Development in Biotechnology



Our use of the regional biotechnology milieu concept stresses that the growth of a strong local biotechnology industry cluster cannot generally be explained by the existence of any one particular locational factor. Rather, various locational factors contribute together to the growth of the milieu; there is no direct tight causal relationship, we suggest, between an individual locational factor and the emergence of a strong local biotechnology industry cluster.

Despite pointing to the milieu rather than individiual locational factors as a source of biotechnology firm clusters, our model does specify what we label as "regional development factors" relevant to the formation of a regional milieu. We specify two main types of regional development factors: cumulative biotechnology assets (which are specialized resources in a *community* necessary for the emergence and flourishing of a biotechnology industry), and the incubating environment (which is necessary to both feed the assets and facilitate their mobilization for the purpose of nurturing a regional biotechnology milieu).

In principle there are probably forces acting between each one of the elements in our model and all of the others, and this could be represented by a complex web of two-way arrows linking each one of them. Figure One, however, seeks to discriminate between those forces which are significant (both empirically and for the purposes of policy initiatives) and those which, while formally identifiable, are not of great interest. The most significant forces included in our model are symbolized by the thick arrows, and represent the processes which most directly lead to the development of local biotechnology industry clusters. The thin arrows in Figure One represent the important feedback processes by which a rich regional biotechnology milieu and strong local biotechnology clusters, once established, may in turn nurture the regional development factors which were preconditions for their emergence.

The model presents public policy as only one element of the incubating environment necessary for the assembly and mobilization of a community's cumulative biotechnology assets, but it also presents the implications of our research for the way in which public policy for economic development in biotechnology ought to be pursued if it is to be successful. Policies, taking on different forms at the various levels of government, should not aim directly at the establishment of biotechnology firms and clusters, but rather should have the following two objectives: (a) the building up of cumulative biotechnology assets in regions where the development of a biotechnology industry is desired; and, (b) the management and mobilization of those assets as a total system of resources for the nurturing of a regional biotechnology milieu. The milieu itself, combined with serendipity and exogenous forces, will lead to the creation and strengthening on local biotechnology industry clusters. The clusters will produce feedback to nurture the regional development factors which undergird the regional biotechnology milieu, but this is not something that policy makers need to direct their attentions towards.

The model evokes the need for additional research to catalogue in detail the ways in which each of the different levels of public policy making ought to function within this schema. For example, the maintenance of a substantial and quality knowledge base in a community (fed through such means as universities and public research institutions) may best be dealt with at a state or national level, while the building-up of specialized hard infrastructure (e.g., a supply of environmentally and scientifically appropriate physical plant and buildings) or combined specialized soft and hard infrastructure (such as a biotechnology research park, incorporating both professional services and physical facilities) might be more suitably handled at the local or state level. Such analysis is beyond the scope of this paper, but we may reiterate two very important policy implications of our reseach at this stage. First, public initiatives aimed at producing economic development from biotechnology should concentrate on the objectives of establishing and sustaining cumulative biotechnology assets in a region for the purpose of nurturing a regional biotechnology milieu. Second, such initiatives should recognize that industrialization in biotechnology tends to take on a regionally specific character, reflecting characteristics of each incubation region, and therefore that policy initiative ought to take into account the strengths, weaknesses and distinctive features of the local regions.

14. Conclusions

Our research has demonstrated that biotechnology, as exemplified by the California biotechnology industry, is not an amorphous, homogeneous, spatially diffuse economic form. Rather, it is highly differentiated in its spatial pattern, character, strength, and relationship with the economic and geographic environment. The "industry", insofar as it may legitimately be referred to as a single industry, cannot be adequately understood unless it is analysed from a regional point of view.

Biotechnology is widely viewed as the new wave of "high technology", likely to play a similar role in the economy and society as that played by electronics and information technology. The fact that biotechnology appears to have emerged in roughly similar general geographic regions to where earlier high technology industry has emerged, has led many observers to presume that the regional economic dimensions of biotechnology will conform to those of other categories of high technology. Our research has shown that, while at the most general level there is some truth to this presumption, as demonstrated by the fact that biotechnology firms tend to be found in the vicinity of the same two great metropolitan regions in California which have been prominent in the development of the microelectronics industry, the biotechnology industry exhibits a distinctive locational pattern.

The paper has shown that the biotechnology industry in California has developed its own regional form. More specifically, we have reached the following two conclusions in response to the research questions posed earlier in the paper: the regional form of one advanced technology industry will not necessarily be duplicated in another advanced technology industry; and, the regional form of a particular advanced technology in one region will not necessarily be duplicated in other regions.

These two conclusions lead to some important themes for economic development policy. First, our research reveals some grounds for hope that those communities which may not have participated actively in other important categories of high technology industry may have a chance of succeeding in biotechnology (or perhaps in some new field of advanced technology still in a nascent form). Second, and as counterpoint to the first theme, biotechnology too requires special regional conditions, and only those communities which manage to assemble the appropriate cumulative biotechnology assets and to maintain a conducive incubating environment, will be able to build a strong local biotechnology industry.

Communities seeking economic development based upon biotechnology are faced with a number of critical *choices*. Most importantly they need to choose between policies which reflect the unique resource base and environment of their region or those which are based upon seeking to emulate other regions. Choices also need to be made between placing attention directly on the needs of biotechnology firms as generators of local jobs and other economic benefits, or on the complexities of building up regionally specific cumulative biotechnology assets. The latter approach is not likely to produce fast results, but our research suggests that it is an essential element of durable technology-based regional economic development.

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Appendix One

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* [Boston: Allen and Unwin, 1986]).

"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 on high technology firms and employment (accurate at 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.