

**DETERMINANTS OF LOCATION AND COMPETITIVENESS IN THE
BIOTECHNOLOGY INDUSTRY: THE CASE OF MASSACHUSETTS**

by

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ABSTRACT

Analysts can examine the locational patterns and competitive advantage of Massachusetts in the biotechnology (biotech) industry in both the R&D and manufacturing phases by using as an analytical framework the synthesis of three theories: the neoclassical location theories, the product life-cycle theory, and new theories on competitiveness. In this thesis, I formulated a theoretical framework applicable to the biotech industry.

Decision makers can derive important policy implications from the theoretical explanations of the behavioral characteristics of the biotech industry. First, an area can be locationally attractive to the young biotech industry if it has a resource base (research-university-medical complex, pool of brainpower, and highly skilled workforce) that would allow innovations to take place. These locational attributes are the result of the incremental build-up in human and physical infrastructure investments. This implies that an area could either maintain its competitiveness or catch up by developing this comparative advantage over time. Second, once the biotech industry matures and becomes product-driven, it is likely to move long distances in search of a cheaper location. The process component, on the other hand, is likely to stay in the innovation center as long as the locational attributes of the area continue to remain competitive.

In the case of Massachusetts, its comparative advantage is clearly in the R&D phase of the industry and its frontier of possibilities should therefore be pushed. On the other hand, the state should develop and create its competitive advantage in the manufacturing phase because more jobs will be created in this activity. The state, however, should neither adopt a *laissezfaire* attitude nor target the industry to enhance its competitiveness. Rather, it should build the capability of its workforce, provide incubator facilities and leveraged financing to start-up firms, and extend institutional support to the industry.

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CHAPTER 1

INTRODUCTION

The biotechnology (biotech) industry has been hailed as the next generation of high-tech industry that will not only provide a strong growth stimulus for local economic development, but, at the same time, will make a nation highly competitive in the global economy. Its emergence from a science to an industry in the late 1970s can be attributed to the unintended consequences of the federal government's support for basic research for biomedical sciences. In those early years, both private and federal grants for basic research were made to a few elite universities which resulted in the development of few major centers of biotech in which these universities are located, namely, California and Massachusetts. These are the same states who have been traditional hosts of high-tech industries beginning with the microcomputers in the 1970s.

The biotech industry is highly concentrated in a few geographic locations. The concentration of the industry near research universities brought about agglomeration economies in terms of the free flow of information and the rapid spread of innovations. The industry is also characterized by a long and costly development cycle eventually leading most firms to form interfirm alliances in order to remain in business and sustain their development efforts.

The potential of the biotech industry to generate income and employment has captured the attention of the private industry and governments, both locally and internationally. On the one hand, the private sector provided the venture capital that

allowed the formation of numerous start-up firms who were solely dedicated to the commercialization of biotechnologies; on the other hand, with the decline of the microcomputer industry in the late 1980s, officials in various states found the emerging biotech industry to be a source of hope in reviving their economies. In 1986, 33 states have various forms of incentives to develop and attract biotech firms to their areas. Even so, the total investment in all states allocated to the biotech firms is only \$147 million, which is actually small compared to federal (\$2.7 billion) and private sector (\$1.5-2.0 billion) investments.

The biotech industry in Massachusetts is one of the largest in the United States, and it is also an important industry within Massachusetts. The state ranks number three (next to California and New York) in terms of the leadership position in the biotech industry. It hosts 10 percent, or 128 firms, of the national total. Although the biotech industry accounts for only 1.3 percent of total private employment in Massachusetts, it has grown faster than the national average of total employment. Most importantly, it is the only industry cluster (together with private health services) in the state that registered positive employment growth between 1988-1991. Moreover, the industry provides wages that are 34 percent higher than the state average (based on 1991 figures). The income and employment multipliers of the industry are also significant.

The biotech industry develops in two phases: (1) research and development (R&D), and (2) application of laboratory breakthroughs into commercial production. Although the state of Massachusetts has undoubtedly become a natural place to locate

for the R&D phase, as shown by the increased formation of start-up firms, the transition of the industry to the manufacturing phase poses some questions on whether the state will continue to be able to get these firms to stay and undertake their manufacturing activities in the region. How will Massachusetts maintain its competitiveness in the biotech industry, not only in terms of hosting R&D biotech firms, but all the way through manufacturing where more jobs will be created for the state?

The purpose of this study is to determine the locational and competitive advantages of Massachusetts in the biotech industry in both the R&D and manufacturing phases. The competitiveness of Massachusetts in the manufacturing phase is as important as the R&D phase because of the number of jobs that will be created by the former activity. In this study, I will assess the locational pattern of each phase in order to shed some light on the important factors that influence the location decisions of firms. I will use this knowledge of the pattern of and likely future trends in firm location and the factors affecting its location decisions to develop a theoretical framework applicable to the biotech industry. Based on this framework, I will draw some policy implications and strategies for strengthening the competitive position of Massachusetts vis-a-vis other states.

Several analysts have confirmed the locational advantage of Massachusetts as a place for biotech firms to undertake their R&D activities, but there have been doubts as to the competitive advantage of Massachusetts in terms of retaining these firms to undertake their manufacturing activities in the area (Feinstein, 1990; Goodwin, Procter,

Hoar, 1991; Porter, 1991; and Malaterre, 1993). These analysts indicate that the difficulty of firms in securing financing both from government and/or commercial banks for the purpose of building their manufacturing facilities may constrain firms in locating their manufacturing activities in Massachusetts.

Goodwin, Procter, and Hoar (1991) and Porter (1991) have also suggested that the state may not be able to supply the type of workers, especially at the entry level, that the industry would need in the event of full-scale manufacturing. Another factor that may constrain the location of firms in the area for manufacturing activities is the attitude of the state towards the biotech industry, which is reflected in the absence of a single agency involved in facilitating and coordinating the industry's interest in terms of financing, marketing, and regulation.

Definition of the Biotechnology Industry

Analysts and policy makers have defined the biotech industry in various ways. The U.S Office of Technology Assessment (OTA) report in 1984 made a generalized definition of biotechnology as "all industrial processes that involve the use of all biological systems," which is a definition that encompasses such ancient processes as brewing and pickling (In Hall, 1987, p. 147). In its 1988 study, OTA made a distinction between old and new biotechnology with the new biotechnology defined as "the industrial use of recombinant Deoxyribonucleic Acid (rDNA), cell fusion, and novel processing techniques" (OTA, 1988). Blakely (1988) further elucidated the definition of the new biotechnology as the use of genetic engineering techniques,

particularly rDNA ¹, to introduce new traits into existing organisms, thus creating new kinds of drugs, diagnostic tools, plants, animals, and industrial processes.

The biotech industry referred to in this study is composed of firms that use a particular subset of techniques that have been developed in the 1970s and 1980s. These techniques include: genetic engineering or the use of "gene splicing" (rDNA); bioprocessing; monoclonal antibodies; protein engineering; and bioinformatics (Hall, 1987).

Research Methodology

In analyzing the locational patterns and competitive advantage of Massachusetts in the biotech industry, I used an analytical framework based on the synthesis of three sets of theories: location theories, the product life-cycle theory, and new theories on competitiveness. Location theories identify the factors that determine why firms locate where they do. Carlton (1979), Markusen et al. (1986), Malecki (1980, 1985); and Hall et al. (1987) basically agree that agglomeration economies, accessibility, and amenities are important determinants for the location decision of high-tech firms. Schmenner (1982), on the other hand, finds business climate to be an important consideration in location decisions. Both Carlton (1979) and Schmenner (1982) find tax incentives to be insignificant criteria for attracting firms to locate in a certain area.

The product life-cycle theory provides a useful, but limited, framework in describing the evolutionary characteristics of the industry and their spatial dimensions.

¹ The rDNA process allows for the production of large, complex molecules called protein, which is the basic building block of life.

According to the Markusen et al. (1986) variant of the high-tech product/profit life-cycle theory, young or innovating industries have the tendency to cluster in specific areas to take advantage of agglomeration economies. In the case of the biotech industry, the transmission of knowledge and information on a day-to-day basis is crucial, thus requiring firms to be situated near each other. Markusen et al. (1986) indicate that, as the industry matures, firms are likely to disperse as they are driven away by the high cost of land and labor. Saxenian (1981) states that the dispersion is done by type of function, while Glasmeier (1985) notes that there are intermediate stages in the firm's evolutionary process. Storper (1985) rejects the idea that there is a single basic path in an industry's development, because there are alternative technological options to mass production, such as those presented by the just-in-time delivery system and flexible specialization.

Porter (1990) and Thurow (1992) present new theories on competitiveness, asserting that locational advantages, such as technology and workforce, are important determinants of competitiveness relative to natural comparative advantages, such as natural resources and capital. Both Porter and Thurow emphasize the limited role of the government in creating and sustaining the competitive advantage of a nation or a region.

In order to examine the relevance of the three sets of theories for the biotech industry, I will use existing surveys of the industry (Feinstein, 1990; and Malaterre, 1993), as well as a survey at the national level (Ernst and Young, 1991 and 1992). I also used studies undertaken specifically for the Massachusetts biotech industry by

Webb (1991); Goodwin, Procter, and Hoar (1991); the Massachusetts Chapter of the Association for Commercial Real Estate (1992), and other published secondary sources (newspaper articles and annual reports) in the analysis. In addition, I conducted interviews with an industry consultant, with representatives at the state level, and with officers of biotech firms to provide qualitative insights into the industry.

Thesis Outline

The thesis is organized as follows. In Chapter 2, I outline the inherent characteristics of the biotech industry to show how certain characteristics of the industry may have influenced their spatial configuration and location decisions. In Chapter 3, I present theories that are important in determining the locational and competitive advantages of Massachusetts in the biotech industry. After developing the synthesized theoretical framework, I trace the locational pattern and the competitive environment of Massachusetts in the biotech industry in Chapter 4. It is also in Chapter 4 that I develop a theoretical framework applicable to the biotech industry. In Chapter 5, I continue the discussion in Chapter 4, by looking at the policies of Massachusetts as they influence its location and competitiveness in the biotech industry. Finally, in Chapter 6, I present the conclusion and policy recommendations.

CHAPTER 2

CHARACTERISTICS OF THE BIOTECHNOLOGY INDUSTRY

The birth of the biotechnology (biotech) industry in the United States from a science to an industry bears resemblance to the genesis of other high-tech industries in the country particularly the microcomputer industry.¹ Its origin can be attributed to the unintended consequences of the federal government's support for basic research in biomedical sciences. Its commercial application has been assisted by the massive inflow of venture capital into the industry, resulting in the formation of start-up firms, particularly in the late 1970s through the mid-1980s.

There are some characteristics of the biotech industry, however, that make it different from other high-tech industries, or, for that matter, from the traditional pharmaceutical industry to which it is often compared because of the industry's concentration in the development of human health-care products. The industry is characterized as having a close association with the university, a long product-development cycle that involves stringent testing and approval process, and high capital requirements. Compared with the computer industry, the biotech industry is not as labor intensive, although its income and employment multipliers are significant.

In this section, I outline the inherent characteristics of the biotech industry and the national structure and spatial location of the industry to put in context the succeeding discussion that will focus on issues at the state level. I will show how

¹ Firms in the microcomputer industry were offshoots of production of defense-related projects (Lampe and Grant, 1992).

certain characteristics of the industry may have influenced how individual firms behave, which then has an effect on their spatial configuration, location decisions, and consequently, their employment potential.

SCIENTIFIC AND INSTITUTIONAL BASE OF THE INDUSTRY

The U.S. leadership in the biotech industry did not happen overnight, but it is the unintended consequence of the congruence of interests among the private sector (industry), the academic community, and the federal government in undertaking basic research in the medical field. The technical base upon which the U.S. biotech industry was founded can be traced back to the initiatives undertaken in the 1930s by Warren Weaver, who was then head of the biology program of the Rockefeller Foundation. Weaver encouraged basic research in biology. Biologists borrowed processes from chemistry and physics, which was later to be called molecular biology, the core discipline for the biotech industry. Project grants were made to top scientists instead of the traditional grants-in-aid to institutions or small grants to individuals (Kenney, 1986). Major research funding was also granted to institutions, but was channelled to a few elite universities, such as Stanford, Harvard, the Massachusetts Institute of Technology, and the California Institute of Technology (Hall, 1987), which enabled these universities to establish molecular biology as a field of study, and provided scientists with funds to equip their laboratories and build-up their research teams.

The institutional arrangements pioneered by Weaver were consolidated under the federal government during World War II; however, it was only after the war that the U.S. government, under President Truman, made it a policy to support research in

medicine and public health. The post-World War II period witnessed the development of a medical research base, which was funded by grants from the National Institutes of Health (NIH) and the National Science Foundation (NSF). Research grants that were formerly extended by the private funding agencies were taken over by federal agencies under a competitive grant system.² Within eight years, the budget of the NIH dramatically increased from \$700,000 in 1940-41 to \$4 million in 1947-48 (Kenney, 1986). Again, most of the federal funding for basic research was concentrated in top universities, which would later provide a critical mass for the development of biotech as an industry; the locations of these universities are almost identical to the institutions that benefitted from Weaver's initiatives.

These institutional developments coincided with the identification of DNA as a substance in 1944 and the historic discovery in 1953 of the structure of the DNA, by scientists James Watson and Francis Crick (Hall, 1987). The major breakthrough in biotech occurred in 1973 when two scientists Stanley Cohen (Stanford University) and Herbert Boyer (University of California of San Francisco) discovered the process of reproducing rDNA (Hall, 1987). This development marked the transition of biotech from a scientific discipline to an industry, whose existence is anchored on its use of numerous subsets of biotech processes that have several commercial and industrial applications.

² Under a competitive grant system, grant proposals from research institutes and universities were evaluated through the peer review process (Kenney, 1986, p. 17).

EMERGENCE OF THE INDUSTRY

The formation of several start-up firms, which were later called dedicated biotech firms ³ (DBFs), signalled the commercialization of products using biotech processes. The DBFs are firms that were formed by venture capital and owner's equity primarily to undertake research and develop commercially viable biotech products. The unique characteristic of these firms is that they are primarily direct spin-offs from university research (Hall, 1987). This situation implies that although principal scientists are involved with biotech firms in the commercialization process, they continue to remain in their academic posts. This arrangement is unlike other high-tech innovation-based industries, such as computing, where key personnel left the university to found their own firms (Hall, 1987). The establishment of Genentech in 1976, under the leadership of Herbert Boyer, the scientist, and Robert Swanson, the venture capitalist, provided a model of university and industry partnership.

The formation of DBFs started in the late 1970s and lasted through the mid-1980s. By the mid-1980s, established pharmaceutical firms had joined the industry, forming linkages with existing DBFs, primarily through strategic alliances. DBFs who are now in different stages of development require assistance from these established firms either in the form of capital or organizational expertise, such as marketing and sales.

³ They are also called new biotech firms (NBFs), a term that is used interchangeably with DBFs to differentiate them from large and established pharmaceutical and chemical firms who joined the industry in the mid-1980s.

SOURCES OF FUNDING OF THE BIOTECHNOLOGY INDUSTRY

The biotech industry relies primarily on two sources of funding, federal grants for the research and development phase and private financing for the commercialization phase.

Federal Grants

Historically, the federal government has provided the major source of funding for research and development related to biotechnology. Government funding of biotech was estimated to be \$520 million per year between 1982 and 1983, and by 1987, the estimated level increased to \$2.7 billion.⁴ From among the federal agencies who provided support for biotech, the most important agency is the National Institutes of Health (NIH), which is the government's largest nonmilitary research agency. In 1987, NIH provided \$2.3 billion of federal support for biotech research and development, which is 85 percent of total government funding of biotechnology.

Federal support for the commercialization of biotech, however, has been minimal compared to the total requirements of the industry. Government grants to the industry are made through the Small Business Innovation Research (SBIR) program. The program, which was created under the Small Innovation Act in 1982, was designed to encourage technological innovation in the private sector and the commercialization of innovations developed from federally funded research. Under

⁴ The total amount includes funding from 12 federal agencies plus contributions to Small Business Innovation Research program.

the Act, federal agencies with extramural research funds⁵ greater than \$100 million are required to allocate 1.25 percent of their funds for the SBIR program.

Participating agencies include the Departments of Agriculture, Commerce, Defense, Education, Energy, and Health and Human Services, among others. From 1983-1988, the program awarded about \$1.4 billion, of which \$150 million was awarded to biotech firms, representing approximately 11 percent of total grants (Groet in Ono, 1991). More than 90 percent of these funds came from the Departments of Defense, Health and Human Services, and the National Science Foundation (OTA, 1988).

Private Sources of Financing

Biotech firms have relied on private equity and venture capital for the majority of their needs. There is, in fact, no other country in the world that successfully uses venture capital in the formation of new biotech firms or start-ups.⁶ As firms mature (and depending on the stage of their development cycle), their reliance on other sources of private financing increases, which take several forms, such as equity, debt financing, and strategic alliances. From 1976 to 1986, investors put in more than \$3 billion into biotechnology, of which about 80 percent was raised by 10 companies (OTA, 1988).

⁵ Federal agencies like NIH and NSF extend grants to research institutes or universities outside its system (extramurally) under a competitive system (peer review process).

⁶ The United Kingdom tried to emulate the United States in using venture capital to form biotech firms, but with limited success. Biotech firms in countries such as Japan and Germany are dominated by established pharmaceutical firms.

Strategic alliances with one or two firms is one of the most important forms of interfirm association in the biotech industry and the one most resorted to by firms who are already in an advanced stage of commercialization. The alliance is generally between a DBF and an established pharmaceutical firm, or another DBF. The alliance generally takes place when the DBF does not have sufficient resources to withstand the long and costly process of development and/or the internal capability to become a fully integrated company. Established firms are more than willing to form relationships with DBFs in order to access the potential benefits of the technology, and, in the end, they develop the expertise where they do not have the in-house capability. Recent studies have also shown that smaller firms are more efficient than in-house research in established firms, giving additional reasons for the latter to link with DBFs (Blakely and Nishikawa, 1992). The alliances could take several forms: equity purchase, licensing agreements, marketing agreements, manufacturing agreements, research contracts, or joint ventures. Table 2.1 shows that in 1989 marketing and licensing agreements account for a large share of strategic alliances made by DBFs.

Licensing agreements with large, established firms may have implications for the employment potential of the industry if they become a permanent solution for capital generation. Some firms have become "research boutiques," whose sole purpose is to develop products for commercialization, but who have no intention of becoming

fully integrated firms.⁷ Licensing the technology to established firms who are located outside the research and development (R&D) location, either in another state

Table 2.1. Types of Strategic Alliances

Type of Relationship	Number	Percentage
Grant	67	4
Joint Ventures	97	6
R&D Agreement	143	8
Development Agreement	303	18
Research Agreement	157	9
Supply Agreement	54	3
Manufacturing Agreement	103	6
Marketing Agreement	379	22
Licensing Agreement	315	18
Unspecified Agreement	103	6
Total	1721	100

Source: Stephen Barley and John Freeman, "Technical Report: A Preliminary Analysis of Strategic Alliances in Commercial Biotechnology" (Cornell University, Ithaca, NY, 1990). In Blakely and Nishikawa. 1992. "Incubating High-Technology Firms: State Economic Development Strategies for Biotechnology." *Economic Development Quarterly*. 6(3), pp. 241-254.

or abroad, would mean losing the potential benefits of additional employment that will be generated by the manufacturing activity. The same situation could happen if DBFs decide to form alliances with large established firms for the manufacturing component. According to the Ernst and Young study (1990), 17 percent of the biotech companies formed alliances for manufacturing purposes.

⁷ An Office of Technology Assessment survey in 1987 indicates, however, that most firms want to be fully integrated, and one of the reasons for not integrating is the problem of sustained capital inflow.

Blakely and Nishikawa (1992, p. 245) note that strategic alliances "simultaneously bifurcate and bridge the production system from R&D to manufacturing and distribution;" however, they concluded that there was neither a clear pattern of functional allocation between the DBF and the corporate partner nor a discernible geographic pattern of a DBF moving closer to its corporate partner. The indeterminacy of the relationship in strategic alliances is explained by two factors: (1) the relative importance of the types of alliances at different stages of the commercialization phase and (2) the firm's linkages with the resource base (university and research institutes) in the area where it maintains its R&D activity.

PRODUCT-DEVELOPMENT CYCLE

The development cycle of a typical biotech firm is subdivided into three phases: research, development, and commercialization, as shown in Table 2.2. Each

Table 2.2. The Product-Development Cycle

Phase	Type of Development	No. of Years Required	Funding Requirement/ Source of Funding
Research	Product discovery phase; Identification of product for commercialization	0-3 years	\$5-10 million/Venture capital, Equity
Development	Clinical trials; Involves animal and human testing for the product's safety and efficacy	3-4 years	\$25-60 million/ Initial public offering, Corporate partnerships
Commercialization	Introduction of first product to the market	5 years	\$100 million+/ Secondary financing, product sales

Source: In "Evaluating the Credit Worthiness of the Biotechnology Industry," (No date). Prepared for Forest Park City Development by Feinstein Partners, Inc.

phase takes about three to five years to develop and requires varying financial requirements and therefore financing strategies. The research component, or what is also called the product-discovery phase, essentially consists of identifying potential products for commercialization. This phase takes about three years, which could cost the firm somewhere between \$5-10 million, which are sourced from the founders' own money and/or from venture capital. Venture capital figures prominently in the beginning of the company's life, with a DBF typically formed by venture capital.

The second phase, the development period, covers the clinical trial that involves testing for the product's safety and efficacy. This phase takes another three to four years and requires a capitalization of about \$25-60 million, which would generally come from an initial public offering and from a corporate partnership. After the 1987 crash of Wall Street, however, fewer stocks were offered, and only industry leaders were successful in generating funding from this source (OTA, 1991). On the other hand, strategic alliances or corporate partnerships with large pharmaceutical or industrial companies are used by DBFs with inadequate capital or without expertise in operational aspects, such as marketing and sales.

The third phase, commercialization, takes place when the company is ready to introduce its first product to the market. This phase would take another five years and more than \$100 million in financial requirements that are sourced from secondary financing and product sales. Generating funds through product sales is resorted to by DBFs who are in need of additional capital infusion but who want to maintain their independence. Generally, they adopt a two-tiered strategy, which requires that the

firm develop short-and long-term products, with the short-term products expected to generate sales to finance and sustain the development and commercialization of long-gestation products. Genzyme is one case where the two-tiered strategy was successful in maintaining and enhancing a DBF's growth and independence (Feinstein, 1990).

REGULATORY ENVIRONMENT

The biotech industry faces two levels of regulation. The first one is at the federal level where approval of new products is made. The second is at the local level or on-site regulations imposed by respective local governments where the biotech facility is located.

At the federal level, the Food and Drug Administration (for pharmaceutical and diagnostics) must approve a new drug before it can be manufactured and sold. The process of preclinical and clinical testing on both animals and humans could take about 10-12 years. The rigorous process of review may even result in the nonapproval of the product and may be financially disastrous for the firm. The capital market, which is the industry's principal source of funding, is highly sensitive to the success and failure of a firm's product; and the product's failure to pass through the approval process will therefore diminish the firm's ability to raise funds and to sustain its product-development efforts.

At the local level, the firm could go through a lengthy process of complying with local regulations that involves dealing with a disparate group of agencies. There are states like California that provide their local governments with a primer that guide the latter in formulating regulatory measures for the biotech industry. On the other

hand, states such as Massachusetts allow their cities or municipalities complete flexibility in drawing up their own regulations. A local government that has regulations in place governing biotech industry would facilitate location of new firms.

EMPLOYMENT POTENTIAL OF THE INDUSTRY

The biotech industry is not labor intensive, nor is it expected to generate as much direct employment as the computer and the semiconductor industry (Webb, 1991). It is an industry that requires a highly skilled labor force and provides relatively higher wages. A 1987 OTA survey indicated that DBFs and large corporations in the industry generated 35,900 jobs of which more than 50 percent are accounted for by scientists and engineers.⁸

A study conducted by the Bank of Boston (1991),⁹ however, showed that the employment and income multipliers of the industry are significant relative to other manufacturing activities. Its employment multiplier of 25.5, ranks the industry 48th out of 333 manufacturing industries in Massachusetts, placing it ahead of the semiconductor industry and behind the leather-goods industry. In terms of its earnings multiplier of 0.70, it ranks 31st out of 333 industries positioning it ahead of aircraft manufacturers and behind the computer and industrial control industries. Using a more aggregated classification of 20 industry averages, the employment multiplier of

⁸ The biotech industry does not have a separate Standard Industrial Classification (SIC) code, so that it is impossible to track yearly employment figures except through surveys.

⁹ The study uses the Regional Input-Output Modeling System (RIMS II) model to calculate multipliers and the data used refer only to the state of Massachusetts.

25.5 (with a range of 12.8-31.7) gives the industry a ranking of 5. Similarly, the income multiplier of 0.70 (with a range of 0.37-0.75) places the industry in the 4th place.

The labor-generating capacity of the biotech industry is a function of the industry's stage of development and the type of market segment that it serves; each development phase generates varying levels of employment and different skill levels. Webb (1991), using a case study of 11 biotech firms in Massachusetts, indicates that the number of jobs created in the industry is high in the development and the commercial manufacturing phase. These stages also require relatively low skill levels, which implies that firms would be hiring a higher proportion of those who possess less than a bachelor's degree. The highest increase in employment is expected to occur during the scaling-up process, where the firm shifts production from small to large quantities of output.

STRUCTURE OF THE U.S. BIOTECHNOLOGY INDUSTRY

According to the Ernst and Young study (1992), there are 1,231 biotech firms in the United States who generate a total revenue of \$8.1 billion. These firms are classified according to the primary market segment they serve, namely, therapeutics, diagnostics, agritech, supplier, and others. The market segmentation can be defined as follows:

(1) **Therapeutics** firms are those who develop products for human or animal use that could cure or reduce the effects or incidence of the disease. These include vaccines, immunological products, and biological drug-delivery systems.

- (2) **Diagnostics** firms are those who develop products for determining the presence of various health or disease states, or cultivate cells as a final product.
- (3) **Agritech or agri-bio** firms are those who produce agricultural products used for animals and plants. These consist of companies involved in plant and animal agriculture, biopesticides, aquaculture, marine natural products, and food processing.
- (4) **Supplier** firms are those who produce laboratory products and manufacture equipment for use in the production of other biotech end-products.
- (5) **Other** firms are those who pursue many interrelated activities; often, they also refer to that market segment that is not yet highly developed, such as biomass conversion, waste disposal, and treatment.

Biotech firms (both publicly and privately owned) catering to the human health-care market segment make up 66 percent of the industry total (therapeutics, 38 percent; and diagnostics, 28 percent) and account for more than half of the total industry revenues. The remaining market segment comprises a small, but increasing, proportion of the industry: supplier firms have a 16 percent share; agriculture-biology, 10 percent; and others, 8 percent.

GEOGRAPHIC LOCATION OF BIOTECH FIRMS

Biotech firms are concentrated in few major centers in the United States. Three areas are considered major centers of biotech firm population: the San Francisco Bay Area, the New York Tri-State region, and Greater Boston Area.¹⁰ The remaining

¹⁰ The word "area" will be dropped in succeeding references to San Francisco, New York, Washington, DC, and Boston.

three areas--Los Angeles/Orange County, the Washington DC area, and San Diego-- have relatively fewer, but still a significant number of, firms. By market segment, Boston has the largest population of publicly held health-care-related biotech firms (94 percent); followed by New York (91 percent), and San Francisco (81 percent). In terms of firm size¹¹ (public companies only), San Francisco is dominated by top-tiered and small-size firms (19 and 39 percent, respectively); New York, by small firms (54 percent) and Boston, by both small and medium-sized firms (33 and 37 percent, respectively).

CONCLUSION

The biotech industry shares some similarities with other high-tech industries in terms of its technical base and early industry formation. The development of the U.S. biotech industry is made possible by substantial federal grants for basic research and the massive inflow of venture capital, allowing for rapid application of biotech processes. At the same time, it is different from the firms in other countries in terms of its close association with the university in the development phase, a long and costly product-development cycle, and its interfirm alliances. These inherent characteristics of the industry may influence its spatial distribution and employment potential. The university-industry partnership and the early bias for grant allocation to selected university and research centers have resulted in the geographic concentration of firms into a few areas of the country. The long and costly development cycle has fostered

¹¹ Ernst and Young defines company size in terms of employment size, as follows: top tier (300+ employees); large (136-299); medium (51-135); and small (1-50).

strategic alliances that may affect the spatial location of the manufacturing component of the firm or its potential to generate employment where its R&D facility is located. Although its employment and income multipliers are significant relative to other manufacturing activities, direct employment in the industry is not substantial.

CHAPTER 3

REVIEW OF LITERATURE

An understanding of the main theoretical foundations of industrial location and competitiveness is important in determining the locational factors and competitive advantages of Massachusetts in the biotech industry. In this chapter, I will present theories that have been highly influential in the development of policies to promote, attract, and retain biotech industries in both the R&D and the manufacturing phases. These are: neoclassical location theories,¹ product life-cycle theory, and new theories on competitiveness.

Location theories explain why firms locate where they do. There are numerous studies undertaken in this area from general business location to high-tech location. I will start by briefly looking at traditional location theories and see why these theories are no longer sufficient to explain the location decisions of high-tech industries, such as biotechnology. I will then explore more recent theories on the high-tech industry, such as those developed by Markusen et al. (1986), Hall et al. (1987) and Malecki (1980, 1984), and will also refer to some empirical studies done on general business location decisions by Schmenner (1982) and Carlton (1979).

I will also examine the product life-cycle theory and new theories on competitiveness, both of which provide different arguments on location and competitiveness than the location theories. The product life-cycle theory, which was developed by Burns and Kuznets (Storper, 1985; Norton and Rees, 1979) and resurrected by Vernon (1966), states that industries go through an evolutionary process

¹ I will subsequently refer to these neoclassical theories as location theories.

of development, and as they evolve from one stage to another, they experience variations in locational patterns. The product life-cycle theory has several variants, as exemplified in the empirical studies undertaken by Wells (1972) in international trade, Norton and Rees (1979) in explaining the core-periphery relationship in the Manufacturing Belt, and Markusen et al. (1986), Glasmeier (1985), and Saxenian (1981) in developing a locational theory for high-tech industries. Although there are criticisms to the product life-cycle theory as being essentialist (Storper, 1985), it provides a useful, but limited, framework for predicting the locational pattern during the industry life-cycle.

New theories on competitiveness posit the importance of human comparative advantage as opposed to natural advantages of nations and regions. As suggested by Thurow (1992), technology and highly educated and a skilled workforce are the two most important bases for the 21st century competition. Porter (1991), on the other hand, added to Thurow's list infrastructure and marketing and service networks.

Table 3.1 provides a summary of these theories, which I will review in detail in this chapter. After reviewing the above theories, I will provide a synthesis of the location and competitiveness determinants, that will provide a framework of analysis in the succeeding chapter.

Table 3.1. Summary of Theories

THEORY	AUTHOR (YEAR)	DESCRIPTION
Location Theories	Traditional Location Theories (e.g., Weber)	Consider transportation cost as the most important location factor.
	Markusen et al. (1986)	State that firms locate where they do based on consideration of accessibility, amenities, and agglomeration economies.
	Hall et al. (1987)	Argue that biotech firms cluster around major research institutes and universities.
	Malecki (1980)	States that R&D activities locate in large cities where professional and a highly skilled workforce are available. Availability of workforce is contingent on amenities and agglomeration.
	Malecki (1984)	Indicates that standardized activities are highly mobile and likely to migrate to low-wage areas; nonroutine activities or those innovative products are likely to remain near R&D location.
	Carlton (1979)	Suggests that location decisions of new firms are influenced by wages and agglomeration economies; technology-based firms including technical branch plants require technical expertise. Taxes and business climate are not important locational factors.
	Schmenner(1982)	Concludes that taxation and financing do not affect location decisions of firms. Relocating plants move long distances and are affected by several locational factors that include tax incentives and reduction in land and labor costs. Business climate plays some degree of importance in location decisions.
Product Life-Cycle Theory	Markusen et al. (1986) Variant: Product/Profit Life-Cycle	Propose that industries go through a four-stage evolutionary process of development, from innovation to rationalization. As they evolve, they experience variations in growth rates, profitability, occupational mix, market power, and locational pattern.
	Saxenian (1981)	States that the distance of the firm's dispersion is a function of the activity being dispersed. More complex manufacturing is moved to shorter distances while assembly-line production is located in Third World countries.

THEORY	AUTHOR (YEAR)	DESCRIPTION
Product Life-Cycle Theory	Glasmeier (1985)	Indicates that there are intermediate stages in the firm's evolutionary process. Technical branch plants generally move intraregionally.
	Storper (1985)	Critiques the product life-cycle theory. Rejects the idea that production processes follow only one basic path.
	Porter (1980)	Argues that the product life-cycle theory cannot predict a particular industry's life cycle because of the wide variations in the duration of each phase. Also suggests that industries do not have to go through the whole cycle of evolution because some industries go through series of innovations.
New Theories on Competitiveness	Porter (1990)	States that competitiveness of a nation or region lies in the development of knowledge-intensive and technology-based industries. Cites educated and skilled workforce, infrastructure, and marketing and service networks as important competitive factors.
	Thurow (1992)	Suggests that new process technologies, brain power, and a skilled workforce are the country's competitive advantage in the 21st century. Cites the limited role of government in creating stability and in funding education and skills training.

Source: Author's review of literature.

LOCATION THEORIES²

The traditional theory of industrial location is based on the works by Weber and Hoover, and subsequently by Lösch (Markusen et al., 1986). Weber, for instance, suggests that the location triangle, consisting of materials, labor supplies, and markets, is the basis for the location decisions of firms. Firms locate somewhere in this triangle, depending on the relative weights of factors. This location triangle is reinforced by the growth of agglomeration economies, which tend to attract other related industries. The traditional theory of industrial location places transportation cost, which include transporting heavy inputs to the production area and the finished product to the market, as the most important cost component.

Markusen et al. (1986) argued that labor has a bipolar element in the industry's cost equation. In the nascent stage, the availability of highly skilled labor, rather than labor cost, is more important for the high-tech firm or industry. It is only in the mature stage that labor cost is considered in the location decision of the firm. Transportation costs for materials and final products are minimal in terms of cost per ton, because high-tech products have a high value relative to their weight.

Using 1970s data of various high-tech industries, Markusen et al. (1986) conclude that in the long term, firms locate where they do based on considerations of

² Although it can be argued that the product life-cycle theory is also a location theory, the location theories discussed here are neoclassical location theories. The reason for separating the discussion between these two types of location theories is because the product life-cycle theory provides an alternative framework to the deterministic nature of the neoclassical location theories.

accessibility, amenities, and agglomeration. Accessibility is defined with respect to major transportation networks: interstate highways and major airports; amenity is in terms of the availability of many educational services and good climate (weather); and agglomeration is represented by the presence of a wide range of special services in the area. On the other hand, business climate, which is represented by unionization levels, wage rates, and high living costs, is not found to be a significant variable in the locational decisions of firms. Most important, they found that the generally accepted view that research spending has a great influence on where firm locates was not statistically significant.

Hall et al. (1987) in their study of the location of the biotech industry in the United States note that biotech start-up companies tend to cluster disproportionately around major research institutes and universities from which they were spawned. This is the case of start-up firms located in San Francisco, Boston, and Washington, DC, which reflect basic research activities in Berkeley-Stanford, Harvard-MIT, and the National Institutes of Health, respectively. Older established pharmaceutical firms who are also involved in the biotech industry have remained in their original location, such as the New York-Philadelphia corridor. They suggest that some possible tie-ups between older and new start-up firms are anticipated and may have locational implications.

Malecki (1980) observes that corporate strategies and the structure of technologically based multilocal firms have spatial dimensions. He notes that firms who decide to conduct long-term R&D tend to centralize their activities and are

more likely to locate near their corporate headquarters. In this case, the R&D component of the firm will locate in large cities where professional and a highly skilled labor force are available. The availability of these workers is contingent on other factors, such as the presence of cultural amenities and agglomeration of research activities in the area (which would include allowing alternative job opportunities and "raiding" other firms of their personnel). Although these types of corporate decisions are undertaken by individual firms, its cumulative effect would be to develop specialized regions in specific stages of the product cycle. That is, regions that attract R&D activities are more likely to generate more new and innovative companies, which, in turn, will lead to spin-offs. The region's comparative advantage as an innovation center will therefore be reinforced over time as its technology base continues to expand.

Malecki (1984) states that the location of R&D facilities places importance on the availability of scientific and professional skills, access to air transport, and quality of life (excellent universities and social and cultural activities). He notes that Boston and San Francisco have become traditional centers of high-tech industries despite high taxes and high labor costs because they are attractive to scientists and engineers who are required for R&D work. He suggests that areas that want to catch up in the high-tech race will have to invest in physical and human infrastructure. He notes that standardized production activities are highly mobile and are likely to migrate to low-wage areas; however, those new, innovative products that incorporate technological advances, or what he calls nonroutine activities, are likely to remain close to the R&D

location. These activities will not generate a huge employment base, but will offer a stable source of employment.

There are other analysts who attempt to model various factors in business location decisions. Carlton (1979) reviews different factors that influence location decisions of new firms and branch plants. He argues that young firms are affected by different factors as contrasted with branch plants, with the latter responding more to current economic conditions in their locational choices than the former. He concludes the following: for new firms, wages and agglomeration economies are important locational factors; for technology-based firms, technical expertise is important even for branch plants; and taxes and a favorable business environment do not substantially stimulate new business activity.

Schmenner (1982) examines the effects of taxes and business climate on both new and relocating plants. He concludes that taxation and financing do not affect the location decisions of new firms and relocating plants. He also notes that plants that move long distances (beyond 20 miles of their original location) respond more to tax incentives as well as to other factors that reduce costs, such as labor and land than do those plants that remain close to their original site. He suggests that business climate, which encompasses the attitude of the government to business and the ability of government in managing itself (e.g., fiscal management), plays some degree of importance in location decisions. He concludes that meaningful state assistance to industry would constitute providing institutional support, or, what the author calls, physical aid. These would include access to information on site identification,

securing permits, and provision of physical infrastructure, appointment of a "point person" to help business in cutting through the red tape, and the coordination of business related activities. Schmenner's findings that business climate is important in the location decision of firms provide a contrasting view to Markusen et al.'s (1986) observations. As noted earlier, the latter analysts found that business climate does not affect business location decisions. A closer examination of both studies, however, indicate that the results do not contradict each other because of the different key indicators/variables used to represent business climate. As business climate indicators, Markusen et al. (1986) use unionization levels, wage rates, and high living costs; in contrast, Schmenner employs institutional support to business and responsible fiscal management.

In summary, location theorists provide various explanations of why firms locate where they do. The locational factors identified include transportation cost, accessibility, amenities, agglomeration economies, availability of educated and skilled workforce, and business climate. The theorists also make a distinction between the types of activities that are sensitive to long-distance movements and the forms of incentives to which these movements respond.

PRODUCT LIFE-CYCLE THEORY

The product life-cycle theory was originally conceived by Kuznets and Burns (Storper, 1985; Norton and Rees, 1979) and resurrected by Vernon in the 1960s. For international trade theorists, the development of the theory was a consequence of their dissatisfaction with the Hecksher-Ohlin (H-O) model, also known as the factor-

proportions theory, in explaining international trade patterns (Wells, 1972) when the H-O theory was unraveled by Leontief's paradox.³ At the sectoral level, the theory became the intellectual successor to the systems oligopoly model (Storper, 1985).

The product life-cycle theory, as rediscovered by Vernon (1966), has many variants. Some of the variants depart from Vernon's narrow definition of the product life-cycle, which specifically refer to the life cycle of a particular product, such as that of machine tools. The application of the product life-cycle theory extends towards describing the development stages of industries and international trade patterns. In this section, I will discuss Markusen's version in describing the pattern of industrial evolution.

Markusen et al. (1986) identify a four-stage model of a product/profit life-cycle for the high-tech industry: (1) innovation, (2) market penetration, (3) market saturation, and (4) rationalization. They posit that industries go through an evolutionary process of development, from youth through maturity to old age. This indicates that, as industries evolve from one stage to another, they experience variations in growth rates, profitability, occupational mix, market power, and locational patterns (Markusen, et al., 1986, p. 41).

In its youth or during the innovation stage, the industry is characterized by a

³ Wassily Leontief (1953) in examining the U.S. exports found that the country considered to be a capital-rich country seemed to specialize in labor-intensive exports. This contradicts the two-factor proportion assumption of the H-O model, which states that a country uses its most abundant factor for the production of its exports and will import those products that use scarce factors. The paradox was explained by Leontief himself as resulting from the higher productivity of American workers compared to other countries in the world during the post-World War II period.

host of new small firms, or what are called start-ups, who are preoccupied with the development and commercialization of a product. During this stage, firms undertake some form of production that is customized and continuously changed to accommodate client specifications. The innovation process, therefore, requires highly specialized skills; the industry draws large proportions of specialists, such as scientists and engineers. Firms cluster in specific areas to take advantage of agglomeration economies. The clustering allows firms access to information on a day-to-day basis and rapid transmission of innovations. In the commercialization stage, there is an expansion in the size and composition of the workforce, which would now include management, sales, and production workers. Exceptionally high profits are expected to occur during the commercialization stage, and they are retained by the firm for further investment.

In its maturity (or market-penetration) stage, the industry is more concerned with process than product innovation. As the production process becomes more routinized, it begins to be dispersed to cheaper locations (in terms of labor and land costs), while the corporate headquarters is maintained at the original site. In the early stage of maturation, the plant locations have the tendency to be dispersed to sites within the same region. At this stage, the employment and output remains high although relatively modest compared to the innovation stage. As a firm begins to be concerned with market penetration, the composition of its workforce shifts towards a greater demand for management and sales personnel and a declining need for highly specialized skills.

In the maturity (market saturation) stage, the industry's quest for market share is achieved either through cost-cutting measures or collusion. The decentralization of the production process accelerates, and plants are moved to greater distances drawn by cheaper labor costs, better business climates, and proximity to markets. Output and employment growth are expected to slow down.

In the last stage of the industry's evolutionary process (rationalization), intense competition among firms results from international competition and cheaper substitutes. To survive, firms will diversify their product lines or relocate overseas for lower production costs; consequently, the industry will start shedding its noncompetitive firms, and plant closings and drops in employment will ensue.

The popularity of the product life-cycle theory did not escape criticism from some analysts. There are those whose studies provided some qualifications on the dispersal phase of industries and those who discounted the usefulness of the theory. Saxenian (1981) in her case study of firms in Santa Clara County notes that the distance of the firm's dispersion is related to the type of function that is being dispersed. For advanced manufacturing, the move is spatially a short distance, while assembly-line production is a relatively longer distance, such as the dispersion of production to Third World countries. Glasmeier (1985) examines the establishment of branch plants, which occurs at the intermediate stage of the firm's evolutionary process. She argues that the movement of the firm is generally intraregional as manifested in the creation of Route 128 and Silicon Valley. She notes that these technical branch plants are relatively independent of their parent firms and undertake a

full-range of operations from R&D to production and assembly.

Storper (1985) characterizes the product life-cycle theory as essentialist. He rejects the idea that the causal process of industrial organization, location, and regional development can be identified through the abstraction of an industry's behavioral characteristics at a certain period in time. He considers the evolutionary characteristics, as defined by the theory, as being narrow, temporal, and ahistorical. He questions the assumption that "real technologies follow one basic path, based on increasing standardization, mechanization, and integration, which generate scale economies, reduce transportation costs, and lead to spatial decentralization" (Storper, 1985, p. 269). He points out that the probability of industries changing their production processes in the same way is not likely to happen in the long run. He notes that standardization and mass production being the inevitable final outcome of output production in the product life-cycle theory are now challenged by technological developments. Mass production is just one technological option as shown by the emergence of just-in-time delivery system and flexible specialization.

Porter (1980) also presents arguments against using the product life-cycle theory as a conceptual framework for describing the pattern of industrial evolution. He notes that the theory cannot predict a particular industry's life cycle because of differences in each industry's development path and the varied range in the duration of each phase. He adds that some industries do not have to go through the sequential cycle of youth to old age because they go through a series of product innovations.

NEW THEORIES ON COMPETITIVENESS

The traditional theory of comparative advantage (e.g., Ricardo and the Hecksher-Ohlin model) rely on the natural resource advantages of nations; however, the recent successes of countries who are resource poor (Japan and Germany) have changed the orientation on how people define competitiveness. Competitiveness, however, has no generally accepted definition, nor does it have a generally accepted theory to explain it (Porter, 1990).

Porter (1990, p. 50) suggests that competitiveness is the ability of a nation to compete in industries that require highly complex technology and highly skilled human resources. Thurow (1992, p. 45) presents a similar line of argument by stating that competition in the 21st century is about winning in the seven key industries that require brainpower. Both Porter and Thurow indicate that competitiveness of nations in the postindustrial era is determined by human factors, rather than the traditional basis of natural comparative advantage.

Porter (1990) suggests that the competitiveness of a nation or a region lies in its ability to develop home-grown firms or industries that use the home base as a platform from which to compete globally or nationally. For firms to be competitive, they should have the ability to innovate and to upgrade constantly. The firm's ability to do so is made possible by a home environment that has the requisite elements for developing globally competitive industries. Porter identifies four determinants of developing competitiveness, which form a system he calls a "diamond": (1) factor conditions, (2) demand conditions, (3) related and supporting industries, and (4) firm

strategy, structure, and rivalry.

Factor conditions refer to the presence of highly specialized skills, technology, and infrastructure. These factors can be created, and those that are already existing have to be efficiently utilized, upgraded, and deployed to particular industries that need them. Specialization in these factor conditions are important, because they could not be easily copied by competitors. They should, however, be constantly upgraded to maintain the industry's competitive advantage.

Demand conditions refer to the presence of sophisticated and demanding buyers who provide a creative tension for companies to innovate and to upgrade constantly. For instance, the strength of Massachusetts in biotechnology and medical instruments can be attributed to the presence of world-class medical institutions in the state (Porter, 1991, p. 37).

Related and supporting industries consist of local suppliers of specialized inputs or firms in industries related by technology, skills, and customers. Local suppliers provide an easy access to cost-effective inputs, while related industries serve as partners in joint innovation efforts.

Firm strategy, structure, and rivalry provides a local base where firms try out their innovative strategies. Local rivalry also fosters greater investment and further improvements in products and services.

The diamond system leads to a clustering of industries, which is linked through customers, suppliers, or other forms of relationships. Once clustering is formed, it creates mutually supporting conditions--information and innovations flow freely among

firms; and with clustering, firms can easily overcome the obstacles to upgrading.

Porter cites the role of the government as important in creating the environment in which firms compete. He states that government policies can influence not only the general education system and general infrastructure development but also in specialized areas of training, technological capabilities in universities, and specialized infrastructure to meet the specific needs of industries. Moreover, he notes that state and local regulations and tax policies also have a role to play in creating a favorable business environment.

Thurow notes that the traditional sources of competitiveness, such as natural resources and capital, have already been nullified. Rapid developments in technology allow those countries without natural resources to be less dependent than previously, either by being able to produce more or to use less of the natural resources. In fact, he suggests that lack of natural resources may be advantageous for the nation, because it will be forced to innovate and use the resources more efficiently, as in the case of Japan. Being in a capital-rich country is also no longer advantageous, because capital is highly mobile. Both developed and less-developed countries have almost equal access to capital through global sourcing, which is facilitated by institutional changes (deregulation) and technological advances in telecommunications and computers.

Thurow suggests that new process (inventing and perfecting new processes) rather than product (inventing new products) technologies will be the country's source of human competitiveness in the 21st century. By focusing on new process technologies, the firm or industry will avoid the inevitable path of the product life-

cycle where formerly high-tech products become low-tech as they are standardized and mass produced and then moved to low-wage countries to be produced. New process technologies will, however, require a reorientation of the type of education and skills to be developed. Brainpower and a skilled workforce will therefore be the key and the only sustainable competitive advantage of the nation.

The competition in the 21st century among the three major economic powers of the world: Japan, the United States, and Europe, will be in seven key industries--microelectronics, biotechnology, the new materials industries, civilian aviation, telecommunications, robots plus machine tools, and computers plus software--all of which require brainpower. Thurow suggests that these industries are footloose and can be located anywhere in the world where there is brainpower to develop and sustain them. For these industries to be competitive, the government has a role in providing some measure of stability for industries that are stock-market driven and those that are susceptible to corporate acquisitions; and in assuring that every citizen has the skills necessary to participate in the market. In applying the concept of competitiveness at the subnational level, an analyst/policymaker can argue that a state's competitiveness is driven by the availability of brainpower and a highly skilled workforce. In the case of the biotech industry, it could locate where these factors are found.

Both Porter and Thurow posit the importance of human comparative advantage (technology, educated and skilled workforce) and cite the limited role of the government in fostering competitiveness in nations and regions. Porter, however, provides a longer list of competitive factors that include infrastructure development

and marketing and service networks. In addition, Porter emphasizes the importance of industry clustering in the home environment as a precondition to developing competitive industries that can compete nationally and internationally. Thurow, on the other hand, puts emphasis on developing new process, rather than product, technologies to divert the path of the product life-cycle where maturing industries undertake their manufacturing activities in low-wage Third World countries. In contrast to Porter's notion of clustering, Thurow notes that competitive industries in the 21st century are footloose and can be located anywhere as long as there is an adequate supply of brainpower and skilled workforce.

CONCLUSION

The theoretical foundations of location and competitiveness shed some light on how and why firms or industries locate where they do and what makes a region or nation competitive. Location theories provide a wide range of factors that influence location decisions: accessibility, amenities, agglomeration economies, and business climate. As an alternative to the deterministic nature of location theories, I examined two other sets of theories that provide different arguments on location and competitiveness. The product life-cycle theory provides a useful, but limited, analytical tool in predicting the pattern of spatial dispersion of firms at certain stages of its evolution. On the other hand, new theories of competitiveness provide arguments for what makes a nation or region competitive. The competitiveness factors include development of technology-based industries, availability of brainpower and a highly skilled workforce, infrastructure, marketing and service networks, and a

government that helps in creating an environment that fosters competitive industries. From these various theories, I have identified the following locational and competitiveness factors that would apply to the biotech industry in Massachusetts.

(1) Young firms locate near the source of innovation. They move their nonroutinized, nonstandardized activities short distances or intraregionally (Saxenian, 1981; Glasmeier, 1985; Malecki, 1984). On the other hand, the routinized production that happens when the industry reaches maturity is moved to cheaper locations in terms of land and labor costs (Markusen et al., 1986); and tax incentives (Schmenner, 1982). New firms are affected by wages and agglomeration economies (Carlton, 1979); in contrast, technical branch plants are affected by current economic conditions, and the availability of technical expertise in their location decisions. The business climate, as measured by the attitude of government towards business and the ability to manage itself, is also an important location factor (Schmenner, 1982). Young industries experience high profits and expansion of the size and composition of the workforce.

(2) Agglomeration economies brought about by the concentration of start-ups firms around research universities and medical institutions and among themselves (Malecki, 1980; Markusen et al., 1986; Hall et al., 1987) is an important locational factor. The benefits of agglomeration economies include easy transmission of information and innovation and availability of a wide range of specialized services (Markusen et al., 1986) and availability of alternative job opportunities for spouses and ease of "raiding" other firms of their personnel (Malecki, 1980).

(3) Amenities or quality of life in terms of the presence of excellent universities, social, and cultural activities is another important locational factor (Markusen et al., 1986; Malecki, 1980).

(4) Access to air transport, and/or interstate highway (Markusen et al., 1986; Malecki, 1984).

(5) The determinants of competitiveness are based on having human advantages: technology, and educated and skilled workforce (Porter, 1990; Thurow, 1992). Industry clustering (Porter, 1990) is an important precondition for developing competitiveness among industries. The role of the government is important in ensuring a competitive environment (Porter, 1990; Thurow, 1992).

Using this synthesized analytical framework, I will devote the next chapter to examining the locational and competitive advantages of Massachusetts in the biotech industry.

CHAPTER 4

LOCATIONAL PATTERN AND COMPETITIVE ADVANTAGES OF MASSACHUSETTS IN THE BIOTECHNOLOGY INDUSTRY

In the previous chapter, I presented theories on location and competitiveness and then synthesized them to develop a theoretical framework for analyzing location and competitiveness of Massachusetts in the biotechnology industry. Using this framework, in this chapter, I will trace the locational pattern of the biotechnology industry and the competitive environment in Massachusetts. My analysis will be based on existing industry surveys/case studies conducted in the last few years (Feinstein, 1990; Webb, 1991; Malaterre, 1993), interviews with industry leaders and representatives from the state government, and published secondary data. Based on my analysis, the biotechnology industry has distinct characteristics that cannot be explained by the synthesized framework. Thus, a theoretical framework will be formulated to explain the behavior of the biotech industry and its spatial dimensions. From the theoretical framework, I will draw some policy implications for the biotech industry.

The biotechnology (biotech) firms in Massachusetts are highly concentrated within the Cambridge-Boston area, where the major scientific base of the state is located. The concentration of firms creates agglomeration economies in terms of the free flow of information and rapid spread of innovations. Although proximity to the research base is probably the most important locational criterion for firms undertaking

the research and development (R&D) phase, the reasons for locating manufacturing facilities are different.

CHARACTERISTICS AND STRUCTURE OF THE INDUSTRY

The biotech industry is still a young industry. It continues to be an R&D-driven industry going through the initial phases of product development.¹ Biotech firms who are doing some level of manufacturing could be as high as 30 percent, but those who could be characterized as true manufacturing entities are only about 5-8 percent.²

The biotech industry in Massachusetts is dominated by firms engaged in the development and commercialization of the health-care segment of the industry. Ernst and Young (1992) indicated that this segment accounts for 94 percent of the total market share with therapeutics accounting for 80 percent and diagnostics 14 percent.³ Porter (1991) places the biotech industry in Massachusetts in the health-care cluster. Industries in this cluster, which include hospitals, medical research institutes, medical instruments, among others, are closely interlinked. For instance, the medical instrument and supply companies work closely with biotech industry in the

¹ Based on interviews with Feinstein, President of Feinstein Partners and Gary Long, Vice President of Operations, Cambridge Biotech.

² True or full manufacturing entities are defined as those firms that are already producing to meet a market demand. This is in contrast with those that are still attempting to penetrate or create a market for their products.

³ This refers only to publicly owned companies. For comparison, Malaterre (1993) reported that this market segment accounts for 57 percent of the market (38 percent for therapeutics and 19 percent for diagnostics).

development and refinement of new products and services (Porter, 1991). Moreover, hospitals in the area provide testing services for biotech products going through the clinical trial phase. Boston's Brigham and Women's Hospital, for example, provided testing services for Biogen's hirulog, a blood thinner to treat coronary disease and after orthopedic surgery (Boston Globe, November 17, 1992).

The top 10 biotech firms are in the health-care business, as shown in Table 4.1. From among the 10 companies, four are already manufacturing entities (Genzyme Corp., Genetics Institute, Biogen, and Cambridge Biotech). Although all the 10 firms have recorded revenues, none of them have posted profits. This situation can be attributed to the high cost of process and product development that cannot be recovered immediately after the firm has started to earn revenues from product sales. In addition, the continuous process of developing new products contributes to the losses incurred by a company.

The top ten biotech firms are public companies, and their basic source of financing is therefore through equity. Other sources of funds come from license fees and royalties (Genetics Institute and Biogen) and product sales (Genzyme). In addition, because of the costly and long development cycle, most of them have formed strategic alliances with established pharmaceutical firms in various forms.

Table 4.1. Top 10 Biotech Firms in Massachusetts

Company/ Location	Major Products and Status	1992 Revenue/Loss (in millions)	Employees	
			Total	MA.
Genzyme Corp./ Cambridge	Manufacturing Ceradese and LDL. Ceradese is a drug that treats Gaucher's disease. LDL is used for cholesterol testing. Conducting tests for Thyrogen, a test for thyroid cancer, and drugs to prevent surgical adhesions. Some pilot studies for Cystic Fibrosis therapy to start soon.	\$219.10/- \$30.30	1515	692
Genetics Institute/ Cambridge	Manufacturing Recombinate Factor VII, a genetically engineered drug for hemophilia sufferers. Early human testing underway for BMP-2 and IL-11. BMP-2 is a bone growth factor for fractures and IL-11, a cancer fighting drug to boost blood platelets after chemotherapy.	\$60.44/- \$41.55	750	740
TSI Corp./ Worcester	Providing contract preclinical testing services to U.S. biotech companies. Developing animal models based on genetic engineering to allow for drug testing of AIDS, cancer, and Alzheimer's disease.	\$34.70/- \$11.10	650	200
Biogen Inc./ Cambridge	Licensing Hepatitis B vaccine and Alpha interferon. Human testing underway for Hirulog and Beta interferon. Hirulog is a blood thinner to treat coronary disease and after orthopedic surgery. Beta interferon is a drug used to treat some cancers, genital warts, and some hepatitis.	\$135.11/- \$38.31	358	350
Cambridge Biotech/ Worcester	Manufacturing 60 diagnostics tests including some to check for the AIDS virus, Lyme disease and animal tests.	\$32.90/- \$43.90	345	138
Repligen/ Cambridge	Completed human studies for Replistatin, a drug for Kaposi's sarcoma, a cancer that afflicts 15% of AIDS patients. Completed animal studies on Platelet factor-4, a natural blood protein for use in cancer and cardiovascular therapy. Animal testing for AIDS vaccine.	\$8.60/- \$10.10	285	285
ImmunoGen/ Cambridge	Completed human testing for Oncolysin B, an anticancer drug for some patients in remission after chemotherapy.	\$2.80/- 15.30	178	178

Company/ Location	Major Products and Status	1992 Revenue/Loss (in millions)	Employees	
			Total	MA.
Alkermes/ Cambridge	Developing products to treat central nervous system disorders.	\$8.54/-5.10	136	136
ImmuLogic Pharmaceutical/ Cambridge	Developing vaccine and therapeutics for people allergic to cats, dust mites, and ragweed. Also working with Merck to develop treatments for some diabetes and rheumatoid arthritis.	\$10.63/-8.60	135	135
T-Cell Sciences/ Cambridge	Pending government approval for a diagnostic test for counting white blood cells, used to manage the care of AIDS patients.	\$10.48/-4.65	135	135

Sources: Boston Globe, March 7, 1993; 1992 Annual Reports of each firm.

There are several estimates of the number of firms located in the state of Massachusetts based on surveys conducted by various entities. Ernst and Young⁴ placed the proportion of Boston⁵ biotech firms at 10 percent of the national total or approximately 128 in 1992; an increase of 16 percent over the 1991 period. Other sources of estimates include Feinstein Partners⁶ who estimated them at 118 in 1990, and Malaterre (1993)⁷ who recorded 105 companies in 1992. The health-care cluster accounts for 13 percent of the total private employment in Massachusetts with the biotech industry⁸ contributing 1.3 percent. Although this figure suggests that the biotech industry accounts for a small proportion of the health cluster employment, it has grown 33 percent faster than the national average (Porter, 1991). Most importantly, it is the only industry cluster (together with private health services) that registered positive employment growth between 1988-1991. Moreover, the industry provides wages that is 34 percent higher than the state average (based on 1991 figure).

Malaterre (1993) estimates that total employment in the industry will grow by 38.6 percent, expanding from 13,600 in 1992 to 18,750 in 1995. Direct employment

⁴ Ernst and Young is an accounting firm who tracks the industry's performance on an annual basis more at the national than state level.

⁵ Biotech firms located in Massachusetts are referred to as Boston-based firms.

⁶ Feinstein Partners does the most extensive tracking of the biotech industry in Massachusetts. Feinstein's survey in terms of market segmentation is comparable to that of Ernst and Young (based on an interview of Feinstein by this writer).

⁷ Malaterre conducted the survey for his master's thesis. The low figure can be accounted by his exclusion of the suppliers category.

⁸ Under this classification, the biotech industry is combined with medical instrumentation.

is expected to grow more rapidly, reaching 30,000 by the year 2000. Malaterre's estimates, however, are linear projections and do not take into account possible changes in the industry resulting from additional firm creation/location or migration out of the state. In contrast, Cambridge Systematics (Report of the Association for Commercial Real Estate, 1992) forecasts that direct industry employment could reach as much as 32,170 (low estimate) or 80,000 (high estimate) by the year 2000. Both direct and indirect employment are estimated to go as high as 140,000 by 2000.

In 1992, the top 10 biotech firms directly employed 2,989 people in Massachusetts or 22 percent of the estimated direct employment of the industry. It is interesting to note, however, that firms who are already into full manufacturing, such as Genzyme Corp., TSI Corp., and Cambridge Biotech, have a relatively dispersed labor force across the country (Table 4.1). In comparison, firms that are basically doing R&D have a labor force base located solely in Massachusetts. Total revenues of the industry were estimated at \$471 million, which is up by 52 percent over the previous year; ranking Massachusetts number three in the country next to San Francisco and Los Angeles/Orange County.

In summary, the biotech industry in Massachusetts is still a young industry and continues to be R&D-driven. It is characterized by firms engaged in the development and commercialization of the health-care segment of the industry. The top 10 biotech firms in Massachusetts are all in the health-care business. The percentage of biotech firms already doing some level of manufacturing could be as high as 30 percent, but those who are true manufacturing entities are only about 5-8 percent. Although the

industry accounts for 1.3 percent of total private employment, it expands faster than the national average. Most importantly, it is the only industry cluster in Massachusetts that registered positive growth between 1988-1991. Its income and employment multipliers also rank high relative to other industries in the state.

SPATIAL DISTRIBUTION OF THE BIOTECH INDUSTRY

Biotech firms undertaking the R&D phase are highly concentrated in the Cambridge-Boston area and Worcester. More than one-third of the industry, in terms of the number of firms, are located in the Cambridge-Boston area, with Cambridge alone accounting for more than one-fifth. The rest of the firms are distributed sparsely among more than 11 locations in Massachusetts (Table 4.2). Worcester became an important site of biotech activities with the establishment there in 1986 of the Massachusetts Biotech Research Park (MBRP). MBRP serves as an incubator for new companies formed by venture capital firms.

The concentration of the industry in Cambridge can be explained by the attraction of early biotech companies to the area by the preeminence of its research institutions. Major learning institutions in Cambridge, such as Harvard and MIT, provided the core where basic research and development in biotech have been spawned. For some time, 18 Nobel laureates in the biological sciences were actively working in these two institutions (Feinstein, 1990). MIT had hired Salvador Luria to build its program, and Harvard had James Watson; subsequently, both universities attracted several more luminaries in the field of molecular biology. The involvement of the medical community in Boston in biomedical research also contributed to the

attractiveness of the Cambridge-Boston area as a biotech center. The Massachusetts General Hospital, for instance, established itself as the leading medical research center in the biotech field with its multi-million dollar research agreements with Hoescht, Shiseido, and Bristol-Myers/Squibb.

Table 4.2. Geographic Distribution of Biotech Firms in Massachusetts, 1990 and 1992

City	No. of Firms		Percentage Share of Total	
	1990	1992	1990	1992
Cambridge	33	30	28.0	28.6
Periphery of Cambridge (Woburn, Lexington, and Waltham)	8	15	6.8	14.3
Boston (Newton and Charlestown)	13	15	11.0	14.3
Outside of Route 128, Northeast (Andover, Billerica, Bedford)	5	15	4.2	14.3
Southeast of Massachusetts (Hopkinton, Framingham, Wellesley, Norwood, Randolph, and Norwell)	6	15	5.1	14.3
Worcester	5	10	4.2	9.5
Others	48	5	40.7	4.8
TOTAL	118	105	100.0	100.0

Sources: 1990 data: Feinstein survey, 1990. In "Assessment of the Massachusetts Biotechnology Industry." 1992 data: Malaterre survey, 1992. In "An Economic Development Strategy for the Biotechnology Industry in Massachusetts."

Note: The percentage shares in 1990 and 1992 are not comparable because the sample firms and market segmentation used in the two surveys are different. The percentage share is used here to reflect the relative concentration of firms in certain areas of Massachusetts.

The unique partnership of the academic community and industry, where academic members involved in the commercialization of biotech products continue to remain in the university also accounts for the clustering of biotech firms in these areas. Likewise, the nature of the industry, which is knowledge-intensive and

innovation-based, compels the industry to be close to the university and for firms in the industry to be near each other.

The comprehensive regulatory guidelines passed by the city of Cambridge, which are the earliest of their kind in the country, served to reassure the industry that the rules of the game had already been established. This has implications in creating a stable environment for most biotech firms. Even so, the industry is not well understood by the public, and its presence has resulted in numerous and ongoing debates on the impact of the industry on the environment.

Because the state has a long history of hosting high-tech industry, it has also developed a highly sophisticated support- service infrastructure that caters to the biotech industry. The business community--lawyers, accountants, architects and others--is already intimately knowledgeable of the needs of the industry; however, firms with their R&D and corporate headquarters in the Cambridge-Boston area seem to move their production/manufacturing activities to areas within Massachusetts that are relatively cheaper. In interviews by the author, industry executives whom I asked about this pattern confirm that their main consideration in locating intraregionally in areas such as Canton or Norwood is the availability of production space at a relatively lower cost.

LOCATIONAL FACTORS FOR R&D AND MANUFACTURING

Feinstein and Malaterre in their surveys, and Hall and Feldman in their studies confirm that the factors cited above are some of the locational criteria considered by biotech firms in their location decisions for R&D. As cited by Malaterre, the

locational factors for R&D facilities include (1) proximity to universities and medical institutions, (2) availability and cost of expansion, and (3) state and local government attitudes⁹ (Table 4.3).

Table 4.3. Locational Factors For R&D and Manufacturing

Criteria	R&D		Manufacturing	
	Rank	S/W	Rank	S/W
Proximity to universities	1.5	1.1	2.6	1.4
Proximity to medical institutions	1.7	1.1	3.2	1.4
Availability/cost of expansion	2.0	2.3	1.8	2.4
Availability/cost of existing facility	2.1	2.2	2.1	2.3
State government attitude	2.1	2.3	2.0	2.4
Local government attitude	2.1	2.2	2.2	2.2
Cost of living	2.4	2.7	2.1	2.4
Availability/cost of land	2.5	2.4	1.9	2.4
Proximity to R&D facility	-	-	2.0	1.6
Labor cost	-	-	2.1	2.4

Ranked by mean response of total sample (n=40)

Key: S= Strength, W= Weakness

Rank column: 1=very important; 5=not important

Strength/Weakness column: 1= strength; 3=weakness

Source: Malaterre survey, 1992. In "An Economic Development Strategy for the Biotechnology Industry."

Proximity to universities and medical institutions is the most important criterion and coincides with Massachusetts' perceived strength or comparative advantage over other states. The second criterion, availability of space and cost of land, is generally perceived to be a liability or weakness of the state. Massachusetts, particularly Boston, has been considered to be a high-cost area, particularly during the real-estate boom in the early 1980s. There are those, however, who pointed out that with the

⁹ The Feinstein survey in 1990 has identical results with Malaterre's: proximity to university/research institutions and cost of facility/land. Feldman in his study of the California biotech industry also had similar results as those of Malaterre and Feinstein.

recession in the late 1980s, the high cost of space has gone down relatively. Porter would even argue that Boston had always been a high-cost area and its being such does not affect its competitiveness, citing Japan and Germany as high-cost countries who continue to remain competitive (Porter, 1991). The third factor that is deemed important by most firms, the attitude of the state towards the industry, has also been considered a weakness for Massachusetts. The state has historically been perceived to be hostile towards business. Although there were attempts to redress this in the King and Dukakis administrations, the overall climate remains the same as it was twenty years ago (Lampe and Rosegrant, 1992). Feinstein feels that local governments, on the other hand, are less hostile than the state government, with the qualification that the attitude problem of the state refers specifically to the state legislature (Feinstein's interview, 1993).

As the industry approaches more than a decade of its existence, some of the firms are now ready to undertake manufacturing activities and are starting to consider sites for manufacturing. The question is: does Massachusetts have the same locational advantage in the manufacturing phase as it had in the R&D phase?

Malaterre (1993) cited the following locational criteria for manufacturing: (1) the availability of space and cost of land, (2) proximity to R&D facilities, (3) attitude of the state government, and labor costs and cost of living (Table 4.3). What is striking here is that proximity to universities and medical institutions, which is the state's most important comparative advantage, is no longer at the top of the list. Instead, those factors that are considered the state's liability are more prominent in the

locational criteria for the manufacturing phase. The high cost of land coupled with lack of available financing for manufacturing facilities is particularly acute for some firms who are planning or are already in the manufacturing phase (Feinstein, 1990; Goodwin, Procter, and Hoar, 1991; and Malaterre, 1993).

Commercial banks, which are still recovering from the real-estate debacle in the 1980s, are unwilling to finance manufacturing facilities because of the high risks of the business.¹⁰ Banks evaluate the creditworthiness of biotech firms in the traditional way by looking at their balance sheets. Because the industry is still essentially R&D based, firms could not secure large funding on the basis of profitability. Even if banks decide to lend, they tend to look at the project purely as a real-estate loan. However, the core and shell (that is, the physical structure itself) of a biotech facility is only 30 percent of the total cost component with 70 percent accounted for by equipment. If a bank loan is made available, only 30 percent of total funding requirements is accommodated.

There is therefore pressure for the state to intervene and provide support for the industry through loan guarantees. Although the state is supportive in a non-programmatic way, it has fewer resources to offer to the industry now compared to the former administration in the late 1980s.¹¹ However, although it is initially less inclined to provide financial and institutional support to the industry, there is some

¹⁰ Information in this paragraph is based on interviews with Feinstein, President of Feinstein Partners and Gary Long, Vice President of Operations, Cambridge Biotech.

¹¹ Feinstein characterized the present state administration as supportive of the industry, but it does not have the programs adopted by the Dukakis administration.

indication recently of greater responsiveness from the state. The Emerging Technology Fund has been passed by the state legislature, and a biotech Ombudsperson has already been appointed.

The state's attitude has already created a disaffected group of firms that have threatened or have eventually moved their manufacturing activities to other states who are more than willing to offer assistance in exchange for jobs (Rosenberg, May 9, 1992; Rosenberg, June 28, 1992). Alpha Beta Technology Corporation, a Worcester-based biotech firm, is building its manufacturing facility in Rhode Island (Boston Globe, March 7, 1993; NAIOP Report, 1992). The state of Rhode Island is funding 80 percent of the \$31 million construction cost of Alpha Beta's facility, and the manufacturing activity is expected to create at least 200 jobs (Boston Globe, March 7, 1993). The Rhode Island Port Authority and Economic Development Agency put together the following for Alpha Beta: acquired a site, built the facility on a turnkey basis, and floated a taxable bond to finance the facility (NAIOP Report, 1992). Genzyme and Cambridge Biotech for a while entertained the idea of moving its bioprocessing plants to other states. Genzyme was concerned with the state's fiscal management and had to be reassured that there will be no tax adjustments for the next five years. Cambridge Biotech, on the other hand, had a problem in obtaining financing for its bioprocessing facility. The state eventually had to intervene through the Economic Affairs Office and the Land Bank in designing a financing package for Cambridge Biotech that would enable it to construct its facility in Massachusetts (NAIOP Report, 1992).

The second most important locational criteria for the manufacturing phase, proximity to the R&D facility, is the only factor that could dissuade firms from moving out of Massachusetts. This consideration is observed in the study of Malaterre that firms with R&D facilities in Massachusetts would want to remain in the state to undertake their manufacturing activities. For example, some of the top 10 biotech firms in Massachusetts maintain their production/manufacturing plants close to their corporate headquarters and R&D facilities (Table 4.4).

Table 4.4. Location of R&D and Manufacturing Facilities, Top Ten Biotechnology Firms in Massachusetts, 1992

Company	Status	Location/Use	Source of Financing
Genzyme	R&D/Mfg.	Cambridge/R&D Boston/Mfg.	Equity, product sales
Genetics Institute	R&D/Mfg.	Cambridge/R&D Andover/Mfg.	Equity, product sales
TSI Corp.	R&D	Worcester/R&D	Equity
Biogen	R&D/Mfg.	Cambridge/R&D	Equity, royalties, license fees
Cambridge Biotech	R&D/Mfg.	Worcester/R&D and Mfg.	Equity
RepliGen	R&D	Cambridge/CHQ Needham/Mfg.	Equity
ImmunoGen	R&D	Cambridge/R&D Norwood/PD,Mfg. Canton/Mfg.	Equity, license fees, interest income
Alkermes	R&D	Cambridge/R&D	Equity

Sources: 1992 Annual Reports of each firm.

Webb's study in 1991, however, indicates that there is no consensus within the industry that proximity to R&D during the manufacturing phase is crucial. Feinstein suggested that although it is important for the firms to stay close to the R&D facilities during the manufacturing phase, the manufacturing facilities need not necessarily be located in Massachusetts. Locating the facilities in nearby states, such as Rhode Island or New Hampshire, will not be materially remote from the R&D facilities in

Massachusetts, because the physical distance is insignificant (one hour's drive) and modern communication facilities allow for rapid transmission of information. Feldman (1985), in his study of the locational pattern of California biotech, indicated that pilot projects are likely to locate near R&D facilities for monitoring of new processes; however, once firms undertake full-scale manufacturing, the locational factors are changed. Malecki (1985) made the same observation that the unstandardized, nonroutinized component of high-tech industries will likely resist migration to low-wage countries, while the routinized component has greater chances of moving to Third World countries.

In summary, the locational criteria for the R&D phase are different from those of the manufacturing phase. In the case of Massachusetts, its strongest locational attribute (presence of world renowned university-research-medical complex) is also the most important criterion for locating R&D facilities of the biotech industry. On the other hand, location factors, such as availability and cost of space and attitude of the state government, which are considered the weak points of the state, are important considerations in the location decisions of the manufacturing component of the biotech industry. These two factors have already caused some intraregional and intraregional movement. Although the intraregional movement may be good for some depressed areas in Massachusetts, the interregional movement is a loss in terms of potential employment in Massachusetts.

COMPETITIVE ENVIRONMENT OF MASSACHUSETTS

As suggested by Porter and Thurow, competitiveness of an area can be measured in terms of the availability and quality of its human and physical infrastructure that can be tapped and utilized for innovation and knowledge based industries. In Porter's (1991) view, Massachusetts is in a strong competitive position in the biotech industry because it possesses most of the conditions necessary to compete nationally and internationally. It has a pool of brainpower and a highly skilled workforce, world-class educational, medical, and research institutions, and sophisticated buyers of products; however, he points out that although the competitiveness of Massachusetts is assured in the R&D phase, the manufacturing phase is less certain. He suggests that to improve the state's competitiveness it has to do the following: develop degree programs for biochemical/bioprocessing engineering, train for biomedical manufacturing, grant stable funding for R&D, and provide incubator facilities for start-up biotech firms.

A comparative analysis of the top biotech centers in the country using key indicators, such as the level of research funds granted by NIH, number of medical schools, federal laboratories, and biotech centers, shows that Massachusetts ranks only number three relative to California and New York in terms of these indicators.

TOWARD A LOCATION THEORY OF THE BIOTECHNOLOGY INDUSTRY

The empirical observations I made on the locational pattern and competitiveness of Massachusetts in the biotech industry indicate that there are few characteristics of the industry that conform to the pattern that I have identified in the

synthesized theoretical framework developed in Chapter 3. The biotech industry has distinct characteristics from other high-tech industries, such as microcomputers, that require a different theoretical framework to explain its behavior and the corresponding spatial dimensions.

Empirical Observations

The only clear pattern that is discernible in the observations made on the industry is the locational advantage of agglomeration economies for R&D activities. The nascent biotech industry clusters in the Cambridge-Boston area to take advantage of the agglomeration economies of being near institutions where research and innovations are being spawned; where highly specialized skills are to be found, and specialized services, such as venture capital, are to be obtained. Small firms or DBFs still predominate in the industry and are preoccupied with product development.

The expansion of the size and composition (from the existing core of scientists) of the firms' workforce to include marketing and sales people also seems to conform to the product life-cycle theory, which predicts this expansion to occur in the commercialization phase. This is the case, for instance, of Genetics Institute and Biogen, Inc., who have become fully integrated firms undertaking all aspects of operations from R&D, manufacturing, marketing, and selling.

Other behavioral characteristics that are expected of a young industry exhibit varying patterns. Firms who are already at some stage of manufacturing (the commercialization stage) continue to work on product development and expand their product composition. Some firms locate their processing facilities close to the area

where their R&D facilities are situated, while others locate them outside the Cambridge-Boston nexus. There are various reasons for these location decisions. Genzyme, for example, who apparently has greater leverage in the capital market because of its successful products, is building its bioprocessing facility in Boston despite the high cost and lack of state support. Genetics Institute, on the other hand, who has recently acquired 55 acres in Andover as the future site for its corporate headquarters and manufacturing facility, does not consider building its manufacturing facility to be a financial problem.¹² It seems that the recent capital infusion from American Home Products has made the firm less vulnerable to financial difficulties. Biotech Cambridge, in spite of its threat to leave town, has finally decided to locate its manufacturing facilities near its R&D facilities for two reasons: the firm has a lot to lose in terms of its skilled labor force and the state has assisted the firm in finding funds for its manufacturing facilities. In the case of biotech firms who are in advanced stages of clinical trials, the location of their production facilities is influenced by cost considerations. This is the case of ImmunoGen who had located its manufacturing facilities in Canton to take advantage of low-cost facilities.

The industry is posting losses contrary to the pattern suggested by the product life-cycle theory that firms in its youth will be earning exceptionally high profits that are plowed back to the industry for investment. Firms who have products in the market continue to incur huge losses which can be explained by the enormous

¹² Information is based on interview with the Communications Director of Genetics Institute (1993).

investment necessary to develop the product (which is a function of regulation, the uncertainty involved in product development, the highly skilled workforce, and sophisticated equipment requirements) and the long period in which to recoup this investment (which is a function of the specialized market, and competition).¹³

Another manifestation that does not conform to the product life-cycle theory description of a young industry is the limited rationalization that has been undertaken by the early start-ups in the Massachusetts biotech industry. In recent years, both Biogen and Genetics Institute closed R&D facilities in Switzerland and Rhode Island, respectively.

Despite the relative youth of the industry, the dispersal of the industry interregionally and to cheaper locations seems to be happening already. The decision of Alpha Beta to build its manufacturing facility in Rhode Island and retain its corporate headquarters in Massachusetts is a characteristic of a mature industry rather than that of a young industry. As the product life-cycle theory hypothesizes, the firm would continue to locate where there are agglomeration economies for R&D and will not disperse until such time that product development is perfected and the production process is routinized. In addition, cost considerations, such as land, are supposed to be outweighed by the benefits of agglomeration economies. Even Glasmeier's (1985)

¹³ Biotech products that provide diagnosis/cure for AIDS and cystic fibrosis have clearly limited and targeted clientele. Competition exists for biotech products currently under development. For instance, the product being developed by Biogen, hirulog, which is said to be an alternative to heparin, is competing with products being developed by Centecor, Core Therapeutics, and Merck (Boston Globe, November 17, 1992).

theory of an intermediate stage, which is characterized by intraregional dispersion of technical plants, cannot explain the interregional movement of Alpha Beta.

Alpha Beta's premature migration to Rhode Island is pushed by the unfavorable business environment in Massachusetts and pulled by "cheap location costs" where the state of Rhode Island provides almost 80 percent of the building cost. The high cost and long period of product development and the long wait before profits are realized pose a major hurdle for the firm's survival. Firms are therefore more likely to move out of their original location in response to exogenous interventions. This exogenous factor includes an active state that provides a favorable environment for the firm to survive through financial and fiscal assistance as well as institutional support. The decision of a biotech firm to locate outside its R&D facility in its infancy is a major decision and is not just occasioned by the promise of a cheap location. The manufacturing facility of a firm is relatively customized and has to be approved by the Food and Drug Administration. The approval process takes a long time and the facility is capital intensive, so that once the decision is made, it is a long-term commitment for the firm to stay in the location where it chooses to establish its manufacturing activity.

In addition, since routine production has not been perfected, there is also a need for the firm to recruit and train a skilled labor force. The availability of a skilled labor pool is therefore factored in when a firm decides to locate its manufacturing facility elsewhere. Otherwise, attracting a skilled workforce would also be costly and may turn out to be a significant element in deciding whether moving to a cheaper

location is beneficial. This case is aptly illustrated by the experience of Cambridge Biotech who was being lured by other states and was almost tempted to leave for cheaper location. However, it soon realized that the cost of training a new set of workers on site will be more costly than getting a guaranteed loan.

There is also another view expressed by one businessman, who states that the decision to locate manufacturing activities is driven by various considerations among them: cost of building facilities, tax incentives and profit repatriation, and availability of trained workforce.¹⁴ The biotech firm may also form a strategic alliance with another more-established firm for the manufacturing component for either of two reasons: to undertake the entire production or to take up additional production load as a result of increased demand for the product.

From this situation, although from a limited observation, we can deduce that firms attracted to cheaper locations in its relative youth are, in fact, those that are still in the process of setting up their initial manufacturing activities rather than those who are already undertaking some form of manufacturing. The former would not have to incur a higher cost of either moving its trained personnel to a new location or recruiting new ones on site, both of which could disrupt the operations of the firm. The biotech firms who have already started manufacturing near their R&D facilities would be more reluctant to move out of their present location unless the incentives provided to them far outweigh the costs of relocation.

¹⁴ This opinion was expressed by Donald McCarren, President of ImmunoGen.

I, however, argue that state boundaries among New England states are artificial.¹⁵ Artificial in the sense that physical boundaries are surmountable, facilitated through an efficient transportation and communication system. Therefore, firms migrating to these other states are not really decentralizing their manufacturing from their R&D operations. These firms could even draw highly skilled workers from Massachusetts and provided that appropriate amenities could be had in these alternative areas, then this possibility is likely to happen. As was indicated by Markusen et al. (1986) and Glasmeier (1985), technical people can be drawn from other areas, as was observed in the Silicon Valley experience where engineers and other technical people were recruited from the Midwest.

A Theoretical Framework for the Biotechnology Industry¹⁶

The theories I discussed and synthesized in Chapter 3 were not particularly useful in explaining the locational and competitive factors of the biotech industry in Massachusetts. In the following, I therefore attempt to construct a theoretical framework to explain the behavior of the biotech industry and its spatial dimensions.

In its youth, the biotech industry is process-driven. It goes through a series of waves of innovation that spans more than a decade in the beginning, but shortens and occurs at different times in succeeding waves. As the waves of innovation shorten and weaken, the industry will become more product-driven. As this happens, the industry

¹⁵ The same views have been expressed by Feinstein (Feinstein interview, 1993).

¹⁶ This specifically refers to the health-care segment of the biotech industry.

will have entered its maturation stage. As the industry goes through these waves of innovation, it experiences varying levels of profitability, growth rates, and locational patterns. Even as the product-driven component of the industry is attracted to a cheaper location, the process-driven component of the industry will remain in the host area and will continue to generate new process technologies.

The industry locates close to the center of innovation; both its R&D and production base must constantly communicate with each other as well as with external sources the changes and modifications in technologies and processes. Over time, some degree of intraregional dispersion of production facilities will occur as the need for more space becomes greater. Interregional movement, however, is achieved at great cost for the recipient area. The host area of the R&D will continue to experience and attract innovation-based industries, expanding its technological base and further enhancing its seedbed functions and its comparative advantage as an innovation center.

The biotech industry, in its youth, clusters around the source of innovation, the university-research-medical complex. Firms locate near the triangular complex and among themselves in order to take advantage of agglomeration economies. The benefits of agglomeration economies include the free flow of information and rapid transmission of innovations, the availability of educated and skilled workforce, the presence of sophisticated users and support-service infrastructure. The clustering of the industry around the source of innovation is reinforced by the fact that scientists involved in the commercialization phase remain in their institutions, which is unlike

the pattern observed in other high-tech industries, such as microcomputers, where scientists sever their institutional ties to found their own companies.

The young industry is characterized by start-up firms or dedicated biotech firms who are formed by venture capital and owner's equity to develop and refine biotech processes in order to generate new products.¹⁷ The development process is long, lasting for more than a decade, and costly, involving more than a \$100 million. The DBFs formed in the late 1970s through the mid-1980s, or what can be called the first-generation biotech firms, were primarily involved in the development and refinements of various biotech process technologies and techniques, rather than product development. The process technologies that were developed in Massachusetts focused on human therapeutics and diagnostics market segments, reflecting the comparative advantage of the area in the health-care sector. Several first-generation firms were "research boutiques" who are characterized as firms whose sole purpose is to develop processes and license them to more established pharmaceutical firms (e.g., Biogen and Genetics Institutes). Because of the long development cycle and the series of process and product discovery and innovation, these firms do not have profits. However, second-generation firms, who are firms formed after the mid-1980s or who are rebirths of the first-generation firms, having refined biotech process technologies, are developing new products, and are expected to have profits.

¹⁷ As defined in Chapter 1, the biotech industry employs a subset of techniques and processes to develop new products in areas of health-care and agriculture, among others.

The commercialization phase of the industry, which spans more than a decade to be achieved, involves first- and second-generation firms. Rebirths of the first-generation firms are manifested through changes in their corporate strategies from "research boutique" orientation to vertical integration of key operational aspects. Fully integrated firms expand the size and composition of their personnel to include marketing and sales people into their pool of scientific and production workers.

Firms, in order to survive the long development cycle, form interfirm associations primarily through established pharmaceutical firms. These associations, or what are called strategic alliances, take several forms depending on the particular need of the firm at each particular stage of its evolution. In the beginning, first-generation firms resort to licensing their technologies in order to finance their development needs. As they continue to develop new processes and products and become relatively financially stable, they stop being "research boutiques" and consolidate to become fully integrated firms. Other forms of interfirm alliances such as marketing, however, continue to develop depending on the readiness of the firm for full integration.

Firms who are in the commercialization phase locate their bioprocessing facilities close to their R&D facilities to allow for monitoring of new processes. The complexity of the production processes require that highly educated and highly skilled workers are involved even in the manufacturing phase. The considerations for proximity and a highly skilled workforce in the location of manufacturing facilities are, however, tempered by cost considerations, in terms of the cost of facilities. Firms, therefore, are likely to locate their manufacturing facilities intraregionally

(outside the major city) where the facilities can be built or leased at relatively lower costs. On the other hand, interregional movement is likely to occur at great cost to the recipient area. In order to offset the cost of moving, in terms of the distance from the R&D facility and the availability of skilled workforce, the recipient area will have to provide substantial fiscal and financial incentives to the relocating firm. The cost of intraregional movement is also cushioned through efficient transportation and communication networks, narrowing the physical distance of the manufacturing facility from its R&D. The availability of a skilled workforce, either through intraregional recruitment or interregional migration, is also an important consideration.

In its maturity, or when biotech firms develop products that have a sustainable market base, the movement may become more long distance. The biotech industry may adopt the behavior of the traditional pharmaceutical industry. This implies that the industry will become multilocal, with its manufacturing base located where favorable fiscal and financial incentives are found in order for the firm to minimize cost and maximize profits. On the other hand, the corporate headquarters and its R&D facilities will continue to locate where innovations are spawned.

Policy Implications

Policies can be derived from the theoretical explanations of the behavior of the biotech industry as discussed above. For an area to be locationally attractive to the young biotech industry, it has to have the triangular university-research-medical complex that would enable innovation to germinate and flourish. With this requirement, comes the assumption that the area also has a sustainable base of

employees who will provide the critical mass for agglomeration economies. These locational attributes are the result of an incremental build-up of human and physical infrastructure, implying that areas could catch up by developing this comparative advantage over time. The other policy implication is that once the industry reaches maturity, its product component is likely to move long distances in search of better fiscal and financial incentives; with the process component remaining in the R&D base. The R&D host of the industry is faced with a choice of whether to retain both the process and product components of the industry or only the process component. Although the process component will likely continue to stay in the R&D area as long as its locational attributes continue to remain competitive, the product component has different locational requirements that are biased towards cost reduction and profit maximization.

In the case of Massachusetts, it does not have a comparative advantage in the product or manufacturing phase of the biotech industry. The state does not have the experience of hosting biopharmaceutical activities, which occur in states such as those in the New York-New Jersey-Philadelphia region who host the traditional pharmaceutical industry. As indicated earlier in this chapter, the competitiveness of Massachusetts' could be enhanced by developing both human and physical infrastructure that would meet the demand of the industry. However, developing these types of comparative advantage will not be enough to retain the product component of the industry if other states/country bid up the price of relocation.

The state should not compete in the manufacturing phase in terms of providing financial incentives on a one-on-one basis with other states. First, it does not have the resources to do so, and, second, it would be to the advantage of the firm, but not of the state, to start an incentive war. What it should do is to provide a climate for the industry to flourish in both the R&D and manufacturing phases and to provide continuity where the private sector is lagging. In the final chapter, I will discuss state policies as they influence location and competitiveness in the biotech industry.

CHAPTER 5

BIOTECHNOLOGY POLICIES OF THE STATE

Economic development policies of the state influence location and competitiveness. Since the 1970s, the policies of the state with respect to developing and attracting industries have taken different turns. They have evolved from the mere provision of packages of incentives to the more recent notion of creating the right environment for growth and development. In other words, the state should have the right attitude towards industry. Under the new theories on the role of the state, the desired policy goal is to achieve a high and rising level of living of the population. This can be achieved through the development of home-grown industries that can compete nationally and internationally, which would constitute the so-called knowledge-intensive and innovation-based industries.

The general perception is that the state of Massachusetts is anti-business. This notion has been perpetuated in the early 1970s during the Dukakis administration when taxes were raised to support the administration's socially oriented programs (Osborne, 1990). However, the last two decades indicate that there has been a pendulum swing in the state's attitude towards business. Although the state's attitude towards business, in general, and to specific industries, in particular, may have been occasioned by ideological bias and the state's economic position, the state government ultimately gives way to persistent demands from a highly outspoken private sector. In the case of the biotech industry, the state is showing signs of greater responsiveness with the recent enactment of the bill on the Emerging Technology Fund and the

appointment of the Biotech Ombudsman. In comparison with other major biotech centers, Massachusetts does not seem to be lagging behind in providing support to the industry.

In this chapter, I outline the new theories on role of the state in economic development, trace the historical development of state policies on the biotech industries, and discuss the characteristics of state initiatives in the biotech industry including that of two other major biotech centers, California and New York. My review of the range of biotech policies in Massachusetts vis-a-vis other states should provide policymakers with an understanding as to whether state policies have any influence on the location and competitiveness of the state in the biotech industry. I conclude this chapter by providing some policy recommendations for the biotech industry.

HISTORICAL OVERVIEW

Until the 1960s, the federal government played a major role in laying the foundations for the development of the high-tech industries, including biotech, who provided the major source of growth for most states in the 1980s. As discussed in the earlier chapter, federal spending on basic research during the post World War II period built a formidable university-research complex in selected areas of the country that spun off entrepreneurs out of university laboratories. Massachusetts benefited from the windfall of federal spending in defense and medical sciences, with the former resulting in the development and rise of the now legendary Route 128 and the latter resulting in the emergence of Massachusetts as a leader in the biotech industry.

The state did not take an active part in its own economic development until the late 1970s when the structural transformation of the country had hit states in various ways. High unemployment was experienced unevenly, and this therefore had to be dealt with by states in their respective ways. This period was also characterized by increasing demands from the private sector, who had been increasingly threatened by global competition, for a more favorable treatment.

Since the 1970s, the role of the state has taken different turns. In order to develop and attract industries, the state's economic responsibilities have evolved from the classical paradigm of providing incentives to industries (Fosler, 1992) to that of providing the right environment for growth and development. The changed approach to local economic development could be largely due to the fact that smokestack chasing has been found ineffective in engendering growth in the local economy and the realization that home-grown industries who are innovation-based and knowledge-intensive have more potential in surviving a highly globalized economy than those who are not. What emerged was a redefinition of the role of the state in economic development. The state is no longer involved in the planning of economic development, but it has become a facilitator and a catalyst of economic development, and a partner of the private sector.

Osborne (1990, p. 5) in studying the experiences of six states in the last two decades concludes that the primary role of the state government is "to nourish elements that makes innovation possible." These elements would include the following: the intellectual infrastructure, a highly skilled and educated work force, the

quality of life, entrepreneurial climate, and supply of risk capital. In this role, the government would not target specific industries but rather target processes: technological innovation, new business formation, and commercialization of research. In dealing with specific industries, the role of the government is to facilitate the process of innovation not plan economic activities, and to fill the gaps left by the private market. Osborne also notes the important partnership that should exist between the federal and state government in economic development. The power of the state government has limits, and there are tasks that the federal government can do best. These include macroeconomic management, and fiscal, monetary, and trade-policy formulation. The federal government can also assume the responsibility of providing an enormous amount of resources that would help in building the technical base in which industries can compete internationally.

Porter (1991) notes that the process of sustaining the nation's international competitiveness lies in the nation's regions and cities to develop and nurture home-grown industries that could compete internationally. Porter emphasizes that neither a *laissezfaire* nor an industrial policy would be the correct approach in being able to compete internationally. The role of the state is therefore to provide an environment in which firms could achieve an increasing competitive advantage. What determines the region's competitiveness is the ability of its industries to innovate constantly. For these industries to produce leading-edge products the state has to have policies that would develop and sustain a highly skilled workforce, quality infrastructure, and state and local regulations that would respond to the needs of the industries.

Fosler (1992) states that the role of the state is to promote the overall process of economic development. This role carries with it responsibilities that include establishing an effective legal, regulatory, and policy framework; providing basic economic infrastructure (skilled labor force, sound physical infrastructure, and balanced fiscal policy) and the development of institutions to meet its new economic responsibilities.

One of the strategies of economic development that came out of the emerging paradigm as it relates to the biotech industry is the incubator model. The incubator model provides a set of conditions that nurture technological innovations and the formation of home-grown industries. Blakely and Nishikawa (1992) have classified the application of incubator models into three levels: policy, programs, and places. The levels of classification underscore the intensity of the state government's involvement in the biotech industry. Thus, a state government with an incubator policy indicates a basic form of state commitment. As the state develops programs and places, it shows a higher level of commitment to the industry. Under this classification, Massachusetts along with New York state, had been classified as a state with incubation places, thus demonstrating a higher form of state commitment. California, on the other hand, which is the leading biotech center in the country had a relatively lower form of commitment to the industry based on this classification.

THE CASE OF MASSACHUSETTS

In Massachusetts, the partnership between the state and high-tech industry was never been an easy one. In 1978, Governor Dukakis was voted out of office partly

due to the efforts of a group of businessmen who felt that the state was antibusiness (Lampe and Rosegrant, 1992). When Dukakis was voted back into office in 1986, he was a reformed governor responding to the business group with a program of action. In 1990, he came up with programmatic ways of resuscitating the growth of an already faltering economy. Biotechnology was identified as a high growth area. The state provided both financial and institutional support to the industry. It created the Massachusetts Centers of Excellence that facilitated the establishment of the Massachusetts Biotech Research Park in Worcester. The financial support to the industry, however, was not substantial compared to other states in the country such as New York which allotted \$34.3 million in the period 1986-1987. In the same period, the state of Massachusetts allocated only a little more than \$1.0 million to the industry (OTA, 1988) and over the years this amount has declined because of the privatization of the Biotech Center of Excellence. In comparison with other public investments of the state, say in the construction sector, this amount is almost negligible. For instance, state investment in the construction sector over the five-year period (1990-1995) averaged almost \$2.0 billion annually.

The new administration of Weld ushered in a different approach to the industry. Feinstein aptly characterized the mood of the state as very supportive to the industry, but not in a programmatic way ¹. In a sense, the approach is expected to be different because the state has gone through one of the worst recessions in history and does not have as many resources to follow through with certain programs. The other

¹ In contrast with Dukakis' program of action.

explanation could be reasons of ideology, for the present administration is attuned to the workings of a market-driven economy. As one manifestation of this ideological differences, the Centers of Excellence, which were created by the state and mandated to carry out promotion of biotech at the state level, have already been privatized.

POLICIES OF TOP BIOTECHNOLOGY CENTERS

As of 1986, 33 states were directly supporting biotech activities particularly in the area of R&D, training, and development of facilities for research. The state involvement includes a wide range of initiatives and diversity in implementation. However, total state investment in the industry is small compared to the investments made by the federal government and the private sector. In 1987, state allocations for biotech-related activities were estimated at \$147 million compared to \$2.7 billion by the federal government and roughly \$1.5-\$2.0 billion from the private sector (OTA, 1988).

A state often has its promotional base at the Governor's Office of Economic Affairs or the state's Department of Commerce. The level of funding commitment that states offer to develop the biotech industry also varies widely. The top five states that have the highest allocations include New York, New Jersey, North Carolina, Michigan and Florida; with the state of New York topping the list with a multiyear allocation of \$34.3 million (OTA, 1988). In comparison, Massachusetts spent a little over \$1.0 million in 1986 and 1987. State's financing for biotech include drawing from proceeds of state lottery, bond issuance, revenues from natural resource and requiring industry matching grants (OTA, 1988). States extend financial assistance to

biotech firms either directly or indirectly. Indirect assistance include tax incentives, information, and technical assistance.

The top three biotech centers (California, New York, and Massachusetts) in the country have different state programs or initiatives directed at the biotech industry.

California

California, who hosts the largest number of biotech firms in the country, takes a low-intervention approach in the industry (Blakely and Nishikawa, 1992). The state's efforts are basically in the area of regulations through the formulation of guidelines for state and local level regulations, and facilitating interactions among business, government, and the academe.

As early as 1983, the state of California, though not explicitly mentioning biotech, targeted 15 growth industries that include the fields that use biotech processes, such as bioengineering, agricultural technology, among others (Malattere, 1993). The Department of Commerce is in charge in formulating and implementing program areas that relate to the biotech industry. It has developed a comprehensive strategy in three key areas: regulation, economic development activities, and funding grants.

In 1985, an interagency task force was created to facilitate interaction among government, industry, and academe to discuss issues concerning the industry and to formulate public responses to look at these issues (Blakely and Nishikawa, 1992). The task force also undertook the review and streamlining of biotech state permits and regulations. After confirming the adequacy of the permit structure, the task force issued a handbook on permits and regulations that includes clarification of the state's

review process (Malaterre, 1993). The handbook serves as an effective state marketing tool to attract biotech firms (Blakely and Nishikawa, 1989). The task force also issued a primer that is used by local communities as a general framework in their formulation of environmental policies on testing and zoning (Blakely and Nishikawa, 1992). Other than these efforts, the biotech industry does not get special treatment. Instead, it has access to several other fiscal, financial, and institutional support mechanisms that are also made available to other industries. These include the matching grant program that has an annual allocation of \$6-7 million. The program is designed to help applied research projects and to encourage the transfer of technology.

Massachusetts

It was only in 1990, after more than a decade from the formation of the first start-up biotech firm in the state, that the leadership in Massachusetts has identified the biotech industry as a key growth area (Commonwealth of Massachusetts, 1990). The state of Massachusetts does not have a single agency in charge of promoting the biotech industry. It has, however, a disparate set of programs or initiatives that are administered by various state agencies. In most cases, however, two agencies, the Executive Office of Economic Affairs and the Massachusetts Government Land Bank, have been involved in negotiating with biotech firms in the area. For instance, the Emerging Technology Fund will be administered by the Massachusetts Government Land Bank. On the other hand, the Biotech Ombudsperson is based in the Executive Office of Economic Affairs (EOEA). In terms of siting regulations, the state does not have a general framework to guide municipalities or cities in formulating their

regulations. Cambridge is the only city in the state to develop a relatively comprehensive set of regulations based on the National Institutes of Health (NIH) guidelines.

The state government has actively sought the participation of the industry in policy formulation by the formation of the Governor's Council on Economic Growth and Technology in 1991. The Council was composed of 36 representatives of business, labor, and academia, the government, and the sciences. Under the Council, the Subcommittee on Biotechnology and Pharmaceutical Development was asked by Governor Weld to consider specific requirements of the biotech industry. The Subcommittee came up with recommendations on the areas of taxation, education, regulation, and administrative support. Recent initiatives of the state on two fronts, the enactment of the \$15 million Emerging Technology Fund and the appointment of a Biotech Specialist, came out of the recommendations of the Subcommittee. The passage of the bill on the Emerging Technology Fund in the spring of 1993 will help in financing the construction of new manufacturing facilities and the expansion of R&D spaces. Essentially, the Fund enables firms to obtain debt financing for their construction and expansion plans, funds which have been inhibited by the credit crunch in the region. The Biotech Specialist or Ombudsperson is responsible for facilitating the planning, permitting, and siting of new facilities; promoting and attracting new biotech firms to the state; and encouraging the expansion of existing

businesses within the state.²

In terms of financing support for the biotech industry, there is no single funding program that caters specifically to the biotech industry. Even the Emerging Technology Fund could be accessed by other firms falling under the broader category of an emerging industry. Instead, there are incentive programs that are also available to the biotech industry. However, because of the high capital requirements of the industry and its relative youth, the fiscal and financial incentives may not be useful to the industry. For instance, the loan guarantee fund offered by the Massachusetts Industrial Finance Agency (MIFA) up to \$500,000 is not large enough to leverage a multi-million biotech company. Moreover, Massachusetts has the best R&D tax credits in the country, but it only applies to a handful of biotech firms who have marketable products and taxable income (NAIOP Report, 1992). The majority of biotech firms are still in the R&D phase and are not therefore eligible because they do not have incomes.

New York Tri-State

The New York State biotech industry, as defined by Ernst and Young, is comprised of three states: New York, New Jersey, and Connecticut, with New York hosting a large proportion of the biotech firms. New York Tri-State hosts the second largest number of biotech firms in the country.

² The Ombudsperson concept is reminiscent of the business ombudsperson or "point person" who was created in Dukakis' administration in 1978 as a response to the clamor of business people for greater state involvement (Osborne, 1990).

As early as 1982, the biotech industry has been identified by New York state as a key industry (Malaterre, 1993). This policy is supported through the New York State Science and Technology Foundation (NYSSTF). The Foundation is a public corporation established 30 years ago, and it is chaired by the State Commissioner of Economic Development. Its primary purpose is to develop innovative technologies and encourage technology transfer. This is accomplished in two ways. The Foundation provides a venue for the interaction among the different sectors of the community involved in the development of the biotech industry: academe, business, and government. It also provides a wide range of programs for the biotech industry. These include: start-up capital for firms involved in the commercialization of innovative technologies; centers to establish university/industry partnerships for technological innovation; research funds for research at universities and not-for-profit labs; and assistance to small firms to access the federal SBIR program. There are other state-wide programs with loan guarantees of up to \$1.5 million that could also be accessed by the biotech industry.

RECONSTRUCTING A POLICY FOR THE BIOTECH INDUSTRY

The location and competitive advantage of Massachusetts in biotech industry can be attributed to the policies of the federal government on basic research and the state government on local economic development. As already mentioned, federal spending on basic research after World War II was largely instrumental in building a formidable university-research-medical complex that made Massachusetts a natural place for the biotech industry to locate. The potential of the biotech industry in

generating local economic development drew interest from as many as 33 states in the country. Despite this statewide enthusiasm, total state allocation (\$147 million) in 1987 is actually small compared to federal (\$2.7 billion) and private sector (\$1.5-2.0 billion) investments. Specifically, Massachusetts spent only about \$1.0 million in 1987, which ranks it as one of the lowest spenders among states engaged in the development of the biotech industry.

The policy goal of the state in economic development is to achieve a high and rising level of living for its population through higher productivity. One way to do this is to develop home-grown industries that are knowledge-intensive and information-based that can compete nationally and internationally. Drawing from the new theories on the role of the state, the right approach to achieve this goal is neither through free market nor targeting specific industries. The state should instead promote the development of all industries because it is in having a cluster of competing industries that the competitiveness of an area and therefore its productivity is determined. In addition, the state should facilitate the innovation process and fill the gap left by the private sector. What this implies is that the state should ensure that the right environment exists for the biotech industry. Specifically, this means that the human and physical infrastructure needed by the industry are in place and constantly upgraded and that the proper regulatory and institutional framework are provided.

The state should set its priorities right in terms of formulating its policies for the biotech industry. Clearly, the comparative advantage of the state is its seedbed function in innovation and its frontier of possibilities should be pushed. If

policymakers understand the locational and competitive advantage in the industry, as discussed in Chapter 4, they can ensure that its resource base (pool of brainpower, highly skilled workers, and university-research-medical complex) remains competitive vis-a-vis other states and the rest of the world. To be able to do this, the following should be present: sustained infusion of federal R&D funds, collaboration with the industry and the state in the training of skilled workers for the industry, and partnership with the private sector and the state in the provision of the physical infrastructure and risk capital. On the other hand, the state (in collaboration with the industry, the private sector, and the academic community) should develop and create its competitive advantage in the manufacturing phase. Its attempt to develop a comparative advantage in the biomanufacturing phase is conditioned by the fact that more jobs will be created in this activity. However, as was mentioned in Chapter 4, the state should not provide substantial fiscal and financial incentives that would heavily bias the allocation of resources towards the biotech industry. Instead, it should prepare its workforce to meet the needs of the industry and provide institutional support to start-up firms.

CONCLUSION

The state of Massachusetts has a reputation of being antibusiness. Its attitude towards business, however, is historically contingent and is a function of ideological biases and of the state's economic health. In the past few years, the state government has been showing signs of greater responsiveness towards the biotech industry. The recent enactment of a \$15 million Emerging Technology Fund and the appointment of

the Biotech Specialist or Ombudsperson are in the right direction in providing the signal that the state considers the industry an important growth stimulus. In comparison with California and New York, Massachusetts is on par with these two states in terms of creating the right environment for the biotech industry. The state needs to enhance and develop its competitive advantage in the R&D and manufacturing phases, respectively.

CHAPTER 6

CONCLUSION AND POLICY RECOMMENDATIONS

In this study, I assessed the locational and competitive advantages of Massachusetts in the biotech industry in both the R&D and manufacturing phases, using an analytical framework based on the synthesis of three sets of theories: location theories, the product life-cycle theory, and new theories on competitiveness.

Neoclassical location theories identify the factors that determine why firms locate where they do. As an alternative framework to the deterministic nature of the location theories, I examined the product life-cycle theory and new theories on competitiveness. The product life-cycle theory provides a useful, but limited, framework for describing the evolutionary characteristics of the industry and their spatial dimension. The new theories on competitiveness, on the other hand, argue that locational advantages such as technology and workforce are important determinants of competitiveness relative to natural comparative advantages.

My study shows that Massachusetts possesses the locational and competitive advantage in the R&D phase of the biotech industry. Its world-renowned research-university-medical complex, adequate supply of educated and highly skilled workforce, availability of highly specialized services, and social and cultural amenities are some of the locational and competitive factors that tend to reinforce the state's specialization for R&D activities. There are indications, however, that the locational and competitive requirements of the biotech industry in the manufacturing phase are different from those of the R&D phase. These refer specifically to factors that are not the inherent

advantages of the state, namely, the high cost of space and land, the perceived attitude of the state, and the fact that the state does not have the historical experience of hosting biopharmaceutical activities such as that of the New York-New Jersey-Philadelphia region.

The biotech industry has distinctive characteristics (i.e., process-driven, long development cycle, and interfirm alliances) that cannot be fully explained by the synthesized analytical framework that was advanced earlier. In this thesis, I suggest an alternative framework that may be useful in explaining the behavior of the industry, and I draw some policy implications from it. I theorize that the biotech industry, in its youth, is a process-driven industry. It goes through a series of waves of innovation that spans more than a decade, but shortens and occurs at different times in succeeding waves. As the process of innovation shortens and weakens, the industry becomes more product-driven. As this happens, the industry reaches maturation. The product-driven component of the industry is attracted to cheaper locations, while the process-driven component remains in the host area, and it will continue to generate new process technologies. In the industry's youth, firms cluster around the source of innovation, the university-research-medical complex, and among themselves in order to take advantage of agglomeration economies. In its maturity, firms develop products and, having built a sustainable market base, they tend to move long distances to reduce cost and maximize profits. At this stage, the industry may also adopt the behavior of the traditional pharmaceutical industry. This implies that the industry becomes multilocational, with the manufacturing base located where favorable fiscal

and financial incentives are to be found, while the corporate headquarters and R&D facilities continue to locate where innovations are spawned.

Given this framework, the relative youth of the biotech industry in Massachusetts compels firms to remain in the state despite tendencies of some to move interregionally. I argue that the pattern of firm location would be for small production plants to be located intraregionally to meet the twin objectives of proximity to the R&D and to minimize the cost of expansion. This pattern holds even for firms with interfirm associations; in fact, having a more financially stable corporate partner allows the firm greater flexibility in locating near the source of innovation where cost of space is relatively higher. At this development stage of the industry, the migration of firms out of the state can still be prevented through a highly interlinked resource base of human and physical infrastructure.

Analysts can derive policies from the theoretical explanations of the behavioral characteristics of the biotech industry. First, for an area to be locationally attractive to the young biotech industry, it has to have the triangular university-research-medical complex that would enable innovations to germinate and flourish. This assumes that the area also has a pool of educated and a highly skilled workforce who will provide the critical mass for agglomeration economies. These locational attributes stem from the incremental build-up of human and physical infrastructure investments and therefore imply that areas could catch up by developing this comparative advantage over time. The second policy implication is that once the industry matures and becomes product-driven, it is likely to move long distances in search of better fiscal

The results of my study are inconclusive. As pointed out earlier, my study provides theoretical arguments for locational and competitive determinants in the biotech industry. Future analysts will therefore find my study useful if they intend to build an econometric model that they could use to test the significance and relative importance of these locational and competitive factors.

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Peter Feinstein, President, Feinstein Partners.
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Gary Harp, Communications Director, Genetics Institute
Gene Gebolys of the Business Development Office of Massachusetts