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Regional Networks of High-Technology Firms The Case of the Greater Boston Region

Paper

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Abstract

The creation and application of new technologies in the form of new products or new processes is increasingly becoming a collective effort in which firms, universities and research laboratories as well as public and other institutions at various spatial scales are engaged. Some of these "networks" are international or even global, such as strategic alliances and R&D joint ventures, which are undertaken to mobilize complementary assets and to provide distant market access. However, it is at the the local and regional level that the development of technology-based firms is most often stimulated. The example of the Greater Boston region shows that these local links are particularly relevant for newly emerging industries such as the computer industry in the 1960's or the biotechnology industry in the 1980's. Relevant linkages include those to universities and research institutions as well as those to venture capitalists, business services, specialised suppliers and customers. Since very specific knowledge bases, firms and institutions are involved, only few regions of a country can develop such high technology networks. As the industries mature, not just the markets but also the supplier and collaborative linkages become international and global, and the embeddedness of these networks into the region therefore becomes less important.

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1) Introduction

Present economic development seemingly is characterised by a paradox. On the one hand global forces are becoming more important in the sense that more and more firms are acting in response to a world market and are exposed to global competition. The larger firms, in addition, maintain subsidiaries in many countries as well as collaborative links around the globe. On the other hand, there is evidence that within this global economy not just national but also regional and local environments still have a considerable - some argue an even increasing - importance for the competitiveness of firms (Scott 1987, Sabel 1989, Porter 1990).

Particularly in high-tech industries, competitiveness strongly depends on the ability to innovate, i.e. to introduce new products or new processes (Scherer 1992). The long-run viability of regional and national economies depends furthermore on the continuous formation of new firms based on new ideas and technologies. The nature of the innovation process and its organisation, however, are different from the past. Neither the individual innovative entrepreneur nor the single large firm and its R&D department are corresponding to existing models. Technological innovations are increasingly becoming a collective effort in which other firms, universities and research laboratories as well as public institutions become involved at various spatial scales ("networks": Hakansson 1987, Camagni 1991, DeBresson et al. 1991, Maillat et al. 1993).

The existing literature on firm networks is rather segmented. The management and industrial economics literature focuses on international or global alliances, showing that since the 1980s an increasing number of firms in high-technology industries have been engaging in strategic alliances (Hagedoorn and Schankenraad 1990, Pisano 1991, Dibner and Bulluck 1992, Gomes-Casseres 1992). These ventures are undertaken to mobilize complementary assets and to get access to technology and markets, thereby speeding up the introduction of new products. Much of this literature tends to ignore similar but often less formalised linkages at lower spatial scales which may also be highly relevant in the innovation process. The literature

on industrial districts, high-tech regions and "innovative milieux" in contrast focuses on those local/regional institutions and networks (Miller and Cotè 1986, Aydalot and Keeble 1988, Bergman 1991, Pyke and Sengenberger 1992), however, often without recognizing the specific conditions in the respective industries as well as the historic transformation of such networks.

In the following, I want to discuss at first conceptually why networks - and particularly those at the regional level - are relevant for high-technology firms. Then, the role of such institutions and networks for the development of two high-technology industries in the Greater Boston area will be studied. The computer industry was chosen as a mature technology-based industry and biotechnology as a newly emerging one.

2) Conceptual Background

2.1 The high-technology firm and its economic environment

The competitiveness of high-technology firms strongly depends on the technological characteristics of their products and processes. Their goods "...embody relatively intensive research and development inputs, either directly at the final manufacturing stage or through the intermediate goods used in their production" (Scherer, 1992, p.3). They have to innovate continuously in order to stay competitive, thereby relying on internal and external resources, factors and institutions (see figure 1). **Internally**, a commitment to relevant functions such as research, development, design and marketing and their appropriate organisation are required. These functions perform "boundary spanning" tasks, such as technology screening and market monitoring, thus linking the firm to its environment (Aldrich 1979).

From the **external environment**, firms draw special factor inputs, such as highly educated and skilled labor, knowledge inputs and (risk-)capital. In addition, high quality materials and components from suppliers as well as service support (management and technology consulting) are needed. Public policy provides specialised infrastructure for education, transport and communication, thus securing some of those inputs. Furthermore, governments frequently

stimulate innovation through regulations and other direct and indirect forms of assistance.

The **local and regional environment** of a firm is particularly relevant for the labor inputs, for venture capital (Florida et al. 1991), and for those knowledge inputs which are "embodied" in employees of regional firms, universities and research institutions (Miller and Coté 1987, Aydalot and Keeble 1988). In the case of firms this is often practical knowledge and skills (Malecki 1991). Also, services such as engineering, consulting or legal services are frequently drawn from the region since regular face-to-face contacts are involved. In certain regions also supplier and client linkages may be strong (Scott 1988); more often, however, these are national or international. Then, public policies, in particular, have a territorial dimension. Since the 1980s, local and regional governments have become more active in technology policy, both in Europe and the U.S. (Ewers and Allesch 1990, Schmandt and Wilson 1990). There has been a proliferation of programs which are intended either to attract high-tech firms from outside the region, to stimulate the endogenous formation of such firms (through e.g. incubators and science parks), or to facilitate the transfer of knowledge to regional firms (technology extension programs).

As many studies on high-tech regions have shown, the mere existence of such factors in a region does not guarantee dynamic development (Miller and Coté 1987, Stöhr 1987, Aydalot and Keeble 1988, Maillat 1991, 1993, Preer 1992). Of particular importance is the intensity of linkages between firms as well as institutions, triggering common learning processes and the accumulation of knowledge in an area. In many cases these relationships go beyond traditional "arms length" market transactions but show features of more stable "network" relations.

2.2 Innovation networks: between markets and hierarchies

Neo-institutionalists such as Williamson (1985) have pointed out that different kinds of institutions can be "used" by firms in order to coordinate the various transactions required to develop, produce and sell a product. Firms can use the market ("buy" through discrete arms-length transactions) or provide necessary inputs themselves ("make": hierarchical coordina-

tion). As a third option, they can engage in networks with other firms or institutions. These are more durable collaborative relations, such as strategic alliances, cooperations, joint ventures or licensing agreements. They may also include durable vertical relations with suppliers and customers as well as informal relations to firms and institutions (Hakansson 1987, von Hippel 1987, DeBresson et al. 1991, Freeman 1991).[1)]

Internal organisation ("hierarchy") is considered the "best" mode of coordination under stable external conditions when there are significant internal economies of scale or scope involved, when there are internal cumulative effects through learning, or when there is a high risk of leakage of know-how and benefits to other firms. Mowery and Rosenberg (1989) consequently argue that the firm is in principle the "natural" place for R&D projects since it allows the firm to keep leakages low and to appropriate the benefits of R&D investment to a higher degree. Internal organisation, however, has disadvantages under dynamic technological or market conditions since the asset-specific investments such as R&D units, specialised equipment or human skills cannot easily be switched to other uses.

The **market** is an efficient mode in the case of standardised inputs since it allows rapid adjustment to changing external conditions. The use of markets, however, becomes problematic in the case of highly specific assets such as R&D activities or high quality components. It is difficult to secure a high quality of these assets via volatile market relations and, in addition, there is a considerable danger of leakage of know-how and benefits to the other firms.

Networks are more durable relations to selected partners. Therefore they allow a better knowledge of the capabilities and the reliability of partners, as well as of the quality of exchanged assets. Participation in networks also may provide a common understanding of technological problems as well as mutual learning among the actors involved (De Bresson

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1) The boundaries of the network mode both towards the market and towards the firm, however, are blurred and not easy to define. Towards the firm it is blurred since technology or production linkages may be accompanied by equity stakes. Also market relations may turn into de facto network relations once they have endured over longer time. Many input linkages become long lasting relations in order to secure the quality as well as the reliability of deliveries. Lundvall (1988) therefore argues that "pure" market relations (in the sense of discrete "armslength" transactions) are much less frequent than neoclassical economists tend to assume.

1991, Storper 1992). Compared to market relations they allow a better control of partners and thereby keep leakages smaller. Networks are more stable than pure market relations but they also are more flexible than the internal organisation. The following conditions are favouring currently the formation of networks in high-technology industries:

* Major technology shifts render existing knowledge bases of firms obsolete. This occurs particularly with new pervasive technologies (such as microelectronics, new information technologies or biotechnology) that affect many industries. Older firms are often not able to cope with these changes on the basis of their existing know-how. Network links allow the more rapid acquisition of required complementary know-how than internal R&D.

* The increasing speed of technological change and the shortening of product life cycles makes R&D more costly but reduces the time left for its amortisation. Network links allow firms to speed up the processs and to keep R&D cost reasonably low.

* Rapidly changing demand and markets make quality changes more frequent and thereby increase the need for flexibility.

* A higher competitive pressure observed in the 1980s in many industries forced firms to cut costs and to focus on their core business. The development and production of components has therefore been frequently externalised (e.g. in the computer industry or the car industry). The links to these new suppliers often take the form of network relations.

2.3 Networks at the regional level

In principle, networks of technology-based firms exist at various spatial scales. Some of them by their very nature tend to be international or global, since their intention is to go beyond the limits of a region or a country. Alliances and cooperations to open up foreign markets or to tap into highly specialised foreign knowledge resources are of this type (Hagedoorn and Schankenraad 1990, Dibner and Bulluck 1992). Others are biased to the national level, e.g. when improved competitiveness of certain national industries through cooperation is intended. This can be achieved through such networks as national R&D consortia and may include

federal institutions [2]. Also formal industry links of major research universities as well as of federal research laboratories tend to be at a national level.

Under certain conditions, such as the following, networks benefit considerably from geographical proximity and agglomeration, however (see Scott 1987, Sabel 1989, Porter 1990, Storper and Harrison 1991, Saxenian 1991, Bergman et al. 1991, Vet and Scott 1992):

* The requirement of good communication, of a common understanding and of regular face-to-face contacts as is the case in joint research and development or in joint production which includes technology development; the regular and close interaction then goes beyond a "static" division of labour and allows benefits arising from mutual learning (Saxenian 1991, Storper 1992);

* the requirement of close monitoring and control of the partner (e.g. the case of the venture capitalist investing in high-tech start-ups: Malecki 1990);

* involvement trust which is developed through long lasting relations and is favoured by a common cultural background (Sabel 1992);

* involvement of local universities or research institutions which are showing a "regional mission" (e.g. aiming at an upgrading of the regional economy) [3];

* involvement of local, state or semi-public institutions with similar goals such as development agencies or institutions for technology transfer [4].

In regional networks in principle all kinds of firms may become engaged. Storper and Harrison (1991) give examples of networks consisting of large as well as small firms both in

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2) Examples in the US electronics industry are R&D consortia such as SEMATECH and MCC (Microelectronic and Computer Technology Corporation: Alic 1990).

3) There are a number of studies which demonstrate the role and mechanisms through which universities become interlinked with their respecitve regional economies (for an overview see Luger and Goldstein 1990). These mechanisms include direct links to firms such as joint R&D projects, contract research, consulting as well as the establishment of science and research parks, incubators and technology centers. Then, there are more informal links established mainly through former students and graduates who start to work in regional firms or start their own firms.

4) In Europe also regional organisations of industry and labor (industry associations, unions) have become involved in technology related programs in certain regions (e.g. Baden Württemberg, Third Italy). In the US this seems to be less the case.

traditional and in high-technology industries. In some cases large firms organise a system of regional component suppliers (Baden Württemberg, Silicon Valley, Southern California) [5]. In other cases, small firms create regional networks of their own, collaborating in development, design, production and distribution (cases of Third Italy, the Swiss Jura, the Danish Jutland, as well as again Baden Württemberg and Silicon Valley: see Storper and Harrisson, 1991).

Regional networks seem to have a particularly high relevance, however, for the formation of new high-technology firms (Miller and Coté 1987). Relevant linkages include those to finance institutions (venture capitalists), business services (consulting, legal and accounting firms) as well as to suppliers and customers. More and more they include also linkages to universities and research institutions. Many universities are actively supporting and strengthening their ties to the respective regional economies through the promotion of start-ups, of consulting activities and contract research (Sternberg 1988, Luger and Goldstein 1990). New technology based firms are often generated through spin-offs from existing high-tech firms or research institutions. They tend to stay in the region where the founder was formally employed or educated and they frequently keep relations to their incubating firm or institution.

Many of the studies of such dynamic regions with intensive networking are rather "euphoric" and therefore uncritical (for a critical review see Amin and Robbins 1990, Tödtling 1992). Often they are also too general and ahistoric, neglecting the specific competitive situation of an industry as well as the historic aspects of the formation and the subsequent transformation of such networks. Therefore it is of interest to investigate for specific technology-based industries in a region

* which institutions and firms were important actors in a network and have been contributing to the formation and growth of the respective industry;
* how have such networks been changing with the maturing of the industry; and
* how do networks of old and new industries compare: are they highly industry-specific and different or is there also a common or generic part which is passing on accumulated knowledge and skills of the past to the new industry?

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5) See Sabel (1989) and Schmitz (1992) for Baden Württemberg, Saxenian (1991, 1992) for the Silicon Valley and Scott (1992), Vet and Scott (1992) for Southern California .

3) The Case of the Greater Boston Region

The state of Massachusetts and its core area the Greater Boston region [6] for several reasons provide an interesting case to investigate these questions. The region has a long history of industrial development and has seen a series of structural transformations from the early textile industry in the past century to the modern high-tech industries such as the computer and electronic industry along "Route 128" or the new biotechnology industry in Cambridge and Boston (Harrison and Kluver 1989). At the end of the 1980s there were about 3000 high-tech companies in Massachusetts, accounting for about 10% of the state's employment (Rosegrant and Lampe 1992). The region, furthermore, provides a rich institutional environment for high-tech firms as regards universities and educational institutions, research laboratories as well as venture capital and producer services.

In the following, I want to explore to what extent, in addition to excellent factor conditions, these institutions and firms have contributed to the formation and development of two technology-based industries: the computer industry on the one hand and the biotechnlogy industry on the other. These two industries were selected since they are of different maturity and allow us to observe the transformation of networks.

The findings rely partly on available studies and materials (such as historical and recent studies of "Route 128"), and partly on personal interviews with key persons in relevant institutions and firms [7]. In the following, at first those institutions which have triggered technology-based development in the region will briefly be characterised (3.1), then the role of networks relevant for the development of the computer industry (representing a mature industry) on the one hand (3.2) and of the biotechnology industry (representing a newly emerging one) on the other (3.3) will be analysed.

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6) The Greater Boston region is definded here by the counties of Essex, Middlesex, Norfok and Suffolk.

7) Interviews with several key persons in institutions of the respective networks were conducted. They include amongst others the technology licensing offices or related activities at MIT, Harvard and Worcester Polytechnic, the Biotechnology Center of Excellence in Boston, the Massachusetts Biotechnology Research Institute in Worcester, as well as selected venture capital firms and biotechnology firms in Cambridge and Worcester.

3.1 Institutions for high-technology development

Universities

One of the outstanding features of the Massachusetts regional economy is its density of high quality universities. Altogether there are 68 universities and colleges in the state, in which about 100 000 people are employed and 250 000 students enrolled (Porter et al. 1991). The universities function as magnets attracting talented people and the best students from all over the US as well as from foreign countries, many of whom stay in the area after graduation [8]. Two of these universities are particularly well known, but they contrast quite strongly in their relations to industry: Harvard, founded in 1636, being the oldest university in the area, has kept its distance to industry until recently. MIT, founded in 1861, in contrast, has from its start tried to build strong industry-links. Since the beginning of this century it has actively promoted these links through internships of students in industry, faculty consulting for industry, research for industry and government as well as through the encouragement of start-ups [9].

Although both Harvard and MIT have strong impacts on the regional economy mainly through the flow of graduates, consulting and other linkages, none has an explicit "regional mission", like many smaller or public universities in other states do. Instead they have a strong national and international orientation. MIT, in particular, has a large volume of industrially sponsered research, with the majority of its funding coming from companies located outside of Massachusetts (Rosegrant and Lampe, 1992, p. 19). It currently supports industry links through its licensing office and through its industrial liaison program. The licensing office has the goal of speeding up technology transfer from research to industry. Since 1987 between 50 and 80 licensing agreements per year have been set up: in total there are 350 active licenses currently. The estimate is that at most 1/2 of these go to firms in Massachusetts. The indu-

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8) Only about 15% of the undergraduates at Harvard and MIT come from within Massachusetts and about 30% of MIT's graduate students (15% of Harvard's) are from foreign countries. On the other hand, almost 1/3 of MIT's 70000 alumni have settled in New England to work, mostly in Massachusetts (Rosegrant and Lampe 1992, p. 16).

9) Besides MIT, there are other universities in the area supporting industry-links (at a lower intensity) like North Eastern or Tufts University.

strial liaison program grants for a fee a "window on MIT" to firms. Most of the subscribers (235 mostly large firms) are located outside Massachusetts and about 1/2 are from foreign countries [10].

The start-up of companies founded by university alumni is a more local phenomenon. MIT supported these partly through a strong personal engagement of some professors but partly also through organisational provisions. Since the mid 1980s the technology licensing office has helped start-up companies by providing licensing support and by looking for reliable consulting firms and venture capitalists [11]. A study by the Bank of Boston (1989) counted more than 600 total start-ups founded by MIT alumni in Massachusetts, employing about 300000 in total[12]. A close observer of MIT start-ups in a recent study found that the success of those start-ups strongly depends on their technology-link to MIT (Roberts 1991) [13].

Research laboratories (defense research)

A strong stimulus for MIT as well as for the development of other research activities in the region was the attraction of a considerable amount of federal defense money since the second World War. This resulted in the spin-off of several research laboratories from MIT, such as the Lincoln and Draper Laboratories, as well as in the growth of defense contractors such as Raytheon and EG&G. In 1990 all private research laboratories had about 230 000 or 6% of the state's employment (Porter et al. 1991), the majority of their activities being defense related.

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10) Interview with Lita Nelson from the MIT Technology Licensing Office as well as with Rob Brand and Diana Garcia from the MIT Industrial Liaison Office in Dec. 1992.

11) Start-ups are in principle regarded by MIT as the better route for technology transfer, since the young firms are more committed to the new invention. However, only a minor fraction of the arising inventions is suitable for a venture-capitalized start-up. At MIT these are only about 3% or at most a dozen a year (Nelson 1991).

12) Companies whose founders had MIT connections include DEC, EG&G Inc., Teradyne Inc., Analogic Corporation, SoftTech Inc., Apollo Computer Inc., Software Art. Inc., Lotus Development Corporation, Symbolics Inc., Biogen Inc., Analog Devices and Bose Corporation. The 300000 also include employees of these firms outside the state.

13) Roberts (1991) found that those start-ups which were able to draw from MIT research and to transer technology to their firm had a significantly better performance (growth and profitability) than those without.

As in other high-tech regions, this defense research was certainly an important factor for the development of the high-tech sector of the region. It contributed to the formation of firms through direct spin-offs [14] as well as through the building up of a stock of highly trained labor of know how. However, there are also problems involved. First, technology transfer to regional firms remained limited due to the secrecy requirements of defense research and a lack of direct networking (Premus 1990). Second, the large amount of money involved created a considerable dependency from the federal defense department. The negative side of this dependency is felt right now as severe defense cuts and resulting budget and employment cuts in these labaratories are occurring.

Business services and venture capitalists

Massachusetts and in particular the Boston area have a large number of various kinds of business services partly specialised on high-tech firms (consulting, engineering, legal and accounting firms, financial services) as well as venture capitalists. Together in these service industries more than 250000 or 6,5% are employed. These services are more than just a support structure for the regional industry since they export their services to a high degree to other regions and countries (e.g. Arthur D. Little or the Boston Consulting Group) but their density also helps to start and grow high-technology firms in the area.

Boston, along with San Francisco and New York City, is a major center of the US venture capital industry (Florida et al. 1991, Green 1991). In 1988, Greater Boston had about sixty venture capital firms, controlling approximately $2 billion in capital or 12% of the US venture capital assets (Preer 1992, p. 98). These firms are part of a large financial cluster in the region (Porter et al. 1991). The industry emerged in the 1950s and 1960s corresponding to the boom along "Route 128" and it was a major player in the growth of the computer industry in the following years [15]. The firms specialise in certain types of new ventures or industries and

14) The Lincoln Laboratory generated about 60 spin-off companies since its existence (see "Spin-off companies from MIT Lincoln Laboratory", Fourth Edition, 1990); the Draper Laboratory accounted for 55 by the end of the 1980s (Rosegrant and Lampe, 1992, p. 99).

15) The first venture capital firm (ARD) was founded already in 1946 in large part through the efforts of Karl T. Compton, Chairman of MIT, together with industrialists, financiers and members of MIT and Harvard. The

many of them operate in the entire US. Spatial proximity, however, favours the identification and nurturing of new ventures since usually not just the provision of money but also close monitoring and management assistance are involved [16]. Following the crisis of the computer industry, the venture capital industry in Massachusetts has been in decline since the mid 1980s[17].

Public Policies

As stated above, the formation and growth of high tech industries in Massachusetts were strongly related to federal research money, in particular from the defense department. Activities and programs of the state and local governments were less important compared to other high-tech regions, such as the Research Triangle area in North Carolina or Austin and Dallas in Texas. In Massachusetts much of the high-tech growth in the 1950s and 1960s preceded state policies. The state became more active only since the mid 1970s (under Dukakis) and subsequently launched a "Centers of Excellence Program" in the 1980s. This was by and large an effort to decentralise some of the high-tech development from the Boston area to more outlying areas of the state (Ferguson and Ladd, 1988) [18]. Both the rather small size of the program and the short duration (the state support was stopped with the change in government in 1989) preclude stronger effects, however.

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company's most profitable investment was its stake in DEC. "Like the firms it invested in, ARD spun off new enterprises as staff and others connected with the company left to start new venture capital firms. Boston Capital, Palmer, Greylock, Charles River Partnership and Morgan-Holland all have ties to ARD" (Preer 1992, p. 98).

16) Interview with Gloria Doubleday, Vice President, Commonwealth BioVentures Inc. in Worcester, March 1993.

17) Massachusetts' share of funds invested in venture capital companies as well as of venture funds received by new companies has been falling since 1985 (Porter et al. 1991, p. 92). The problem currently is that "too much money is chasing too few projects".

18) This program was launched in 1984 and supported university-based "Centers of Excellence" in Amherst (Polymer), Lowell (Photovoltaic and Polymer), Woods Hole (Oceanographic) and Cambridge (microelectronics at MIT). The program has supported the formation of the Biotech Research Park in Worcester through the provision of grants in critical stages of the project (interview with Fernando Quezada, Director, Biotech Center of Excellence Corporation, Jan. 1993).

3.2 Networks in the computer industry

The dynamics of the regional economy since the 1960s is strongly related to the formation, growth and, since the mid-1980s, decline of the computer industry. At the beginning of the 1990s the computer industry in Massachusetts employed about 28 000 (less than 1% of the overall employment), but it was part of a larger cluster which was made up also of software and data processing firms, electronic components, peripheral manufacturing, informaton technology services, telecommunications and precision instruments. In software and data-processing about 41 000, and in the electronic components another 31 000, were working in 1990. In total, the information technology cluster employed about 100 000 or 2.6% in Massachusetts. According to Porter et al. (1991) the computer industry, software and electronic components industry are strongly interlinked with each other, but linkages are developed also to other industries in the area. The medical industries, universities and research institutes, financial services, consulting and engineering firms serve both as clients and as consultants and cooperation partners.

Many features of the computer industry's development resemble the classical product life cycle (Vernon 1966, Utterback 1979), and this partly relates also to its linkages and networks. After strong growth from the 1960s until the mid 1980s, the Massachusetts computer industry has slided into a severe crisis in the late 1980s. Its largest employers, Digital Equipment Corporation, Wang, Prime and Data General, currently show considerable losses and have to undergo severe restructuring and lay-offs. To a considerable extent these difficulties have to do not just with the nature of their products (betting on the wrong "horse", in this case the minicomputer) but also with the organisation of the innovation and production process. In particular, the strong vertical integration of the largest firms and the abandoning of regional networks seems to contribute to their problems.

Formation and early growth period

The computer industry in the Boston area was started by researchers from MIT (Digital Equipment Corporation: DEC) and from Harvard (Wang) in the 1950s. The firm formation

process accelerated in the 1960s (25 start-ups of computer firms) and in the 1970s (23 start-ups: Saxenian 1992). The growth of these and other high-tech firms (such as electronic products and instruments) occured mainly along "Route 128", a circumferential highway around Boston and Cambridge [19] and was in the beginning strongly supported by military and aerospace contracts [20]. In the 1960s and early 1970s a growing demand for minicomputers and electronic products stimulated the firm formation process. Hundreds of small electronic, component and software firms sprang up, many as suppliers or subcontractors to the minicomputer firms. Regional interfirm-networks thus became more and more articulated during this formation and early growth period (Shimshoni 1966, Dorfman 1983, Preer 1992, Rosegrant and Lampe 1992) [21]. Figure 2 summarizes the main actors and the respective linkages involved in the development of the computer industry along Route 128.

The entrepreneurs came partly from the universities like MIT and other research institutions but partly also from existing firms as second or third generation spin-offs from the pioneers (Shimshoni 1966, Preer 1992) [22]. In many cases not just the entrepreneurs but also knowledge about technologies, management techniques and customers were transfered from those incubating firms and institutions to the new firms (Shimshoni 1966 [23], Roberts 1991). Venture

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19) "Route 128" was originally built to promote recreational access to the north and south. The first section was opened in 1951 and was then called by critics 'the road to nowhere'. This changed quickly into 'the magic semicircle' after about 100 firms had moved there already by 1955 (Rosegrant and Lampe 1992). A number of privately developed industrial parks sprang up and provided the required physical facilities and office space. The area includes the counties Middlesex, Suffolk, Norfolk and Essex.

20) In 1962 federal government purchases accounted for fully half of the sales of Route-128-firms (Saxenian, 1992, p. 45).

21) Interview in may 1993 with John Cullinane, founder of the Cullinet Software Inc., one of the first companies in the region to specialize in computer software products. Preer (1992, p. 97), in addition, finds that "a web of local relations needed by the high-technology industry was developed in the Route 128 technopolis. During the formation of the technopolis, information flowed freely among firms, universities and research institutes. Most of the relations were informal. The intricate connections among MIT researchers and key personnel at DEC and other companies facilitated the high rate of innovation that characterised the emerging computer industry in Massachusetts."

22) Besides MIT and the Research Laboratories the defense contractor Raytheon, being the source of close to 150 start-ups, was one of the most important incubating organisations. Then the computer firms themselves produced spin-offs: Data General, founded in 1968, was a spin-off from DEC; Prime, founded in 1972, was a spin-off from the Boston operation of Honeywell (Preer 1992).

23) Shimshoni (1966) was one of the first to investigate the "embedding" of Route-128-firms into the region more systematically. In a survey covering 151 firms in the instruments industry (including electronic and computer

capitalists, which were still scarce in the beginning (1950s) [24], strongly supported the firm formation process since the 1960s through the provision of capital as well as management monitoring and assistance.

Maturity and decline

During the 1970s the leading minicomputer firms (DEC, Wang, Data General, Prime) grew rapidly, partly through vertical integration in order to realize economies of scale and scope. This was a reasonable strategy at that time, in a period of technology leadership as well as of stable external conditions and growth. The leading firms internalised the production of electronic and mechanical components (e.g. integrated circuits, memory chips, printed circuit boards and disc-drives) as well as much of the operating system and software since they were betting on proprietory instead of open architectures. In doing this, they reduced ties to local subcontractors and other firms and weakened or abandoned the regional network. This consequently reduced both knowledge flows between the firms and joint learning [25].

However, in the late 1970s and early 1980s **conditions in the international computer- and electronic industry had fundamentally changed** (Gomes-Casseres 1992).

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firms) he found that

* most of the new firms were founded near their "parent organisations" (1/3 by former MIT students) from which the technology for the new products was frequently transfered;
* they were to a high degree supported by other firms and institutions from the region providing risk capital, services, technical supplies and information about markets;
* more than half of the firms (56%) cited at least one of the local sources (universities, consultants as well as professional and social contacts) as most frequently used;
* 58% of the respondents mentioned New England as an important center of technology in their fields; and
* 44% indicated New England as their main market center.

24) In the 1950s the Bank of Boston had quickly responded to the capital needs of high-tech companies and had provided finance. They did this with large success since in the early 1960s they had accounts from 85% of the high-tech firms along Route 128 (Rosegrant and Lampe 1992, p. 120).

25) DEC, Data General, Wang and Prime followed the route of vertical integration. According to Saxenian (p. 218 f) "by 1976 Data General made many internal components, from printed circuit boards to core and semiconductor memories. By 1981 ... it was designing and manufacturing more than 80% of the final product they sold". Likewise DEC "by 1983 was internally designing and manufacturing everything from keyboards and display monitors to disk drives, custom integrated circuits, computer memories, printed circuit boards, and power supplies". In contrast to Silicon Valley firms, Route 128 firms also limited labor mobility as much as possible by rewarding long-term staying and careers inside the firms.

* New players had emerged on the global scene (in particular Japanese and other Far Eastern firms), competition strongly intensified, prices fell and the pace of product change sped up.

* Equipment and components became more standardised and almost became "commodities". Consequently the value chain was broken up and newly reorganised (Gomes-Casseres 1992). This also implied a reorganisation in space since new production facilities, particularly for semiconductors, components and peripherals, were frequently located in low wage countries and regions (Gordon 1991).

* The standardisation of components reinforced a trend towards open systems architecture, putting a pressure on the old leading firms (such as IBM or DEC) which had been betting on proprietory systems.

* Finally, there was a trend towards "downsizing", favouring microcomputers and PC-networks. Both mainframes and minicomputers (the principal segment of the Route 128 firms) lost market shares, but the minicomputers were more affected since they got squeezed in between the downsizing mainframes and the growing segment of PC's and workstations.

One of the consequences of these changes was a substantial reduction of the benefits of vertical integration and an increasing importance of "network strategies" both at the global and regional level. At the global level, firms entered into various strategic alliances with other firms of the "triad" (US, Japan and Europe) in order to secure supplies, to trade/develop technologies or gain market access [26]. Firm networks were intensified at lower spatial scales as well.

In the US, computer and electronic firms in the two leading regions, Silicon Valley and Route 128, were strongly challenged by the new situation, and for various reasons they reacted quite differently during the 1980s. [27].

Silicon Valley firms (e.g. Hewlett Packard, Apple Computers, Sun Microsystems, Silicon

26) See Gomes-Casseres (1992) for a more detailed analysis of these international alliances in the computer industry.

27) Saxenian (1992) has provided a very detailed study of this topic, based on 160 in-depth interviews with firm managers and industry representatives in the two regions.

Graphics) started to build more flexible organisational structures (flatter hierarchies, more autonomous subunits) and focused on their respective core capabilities (Saxenian 1991, 1992). Consequently they externalised other activities and functions and thereby rebuilt a dense regional supplier network. Subcontracting relations were changed from the traditional type (buying of components of low complexity at low prices) towards more selective relations of higher quality. The number of subcontractors was reduced but their respective activities became more complex since they included quality control and development [28]. The new relations were based on continuous information exchange and frequently involved joint learning. Due to this networking strategy Silicon Valley firms were faster in developing and prototyping new products [29] and in the end were clearly more successful than their East coast counterparts.

Route 128 firms, on the other hand, did not substantially change their past strategies although their specific product, the minicomputer, got more and more under pressure both from the mainframes and from the PC's and new work stations. They stuck to the minicomputers and the proprietory architecture and stayed rather strongly vertically integrated and hierarchically organised. They did not rebuild regional networks as the Silicon Valley firms did [30]. At the end of the decade, and still today, some of them are in a severe crisis, showing considerable losses and laying off employment on a large scale [31].

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28) "Suppliers were increasingly drawn into the design and development of new systems and components at a very early stage, and became closely integrated into the customers's organisation in the process" (Saxenian, 1992, p. 311).

29) A comparative study concluded that Silicon Valley semiconductor firms founded between 1978 and 1985 could prototype products 60% faster and ship them 40% faster than other firms in the U.S. (Schoonhoven and Eisenhart 1991).

30) Saxenian (1992, p. 5) contrasts the two regions by stating that "Silicon Valley's regional network-based industrial system encourages joint learning and continuous innovation among specialised producers, while Route 128's independent firm-based system is constrained by the organisational rigidities of its leading producers and their isolation from external sources on know-how and information".

A recent survey by Bathelt (1991), covering 160 firms in 5 high-tech regions of the US and Canada, including the Boston area, confirms these findings. The study revealed that, contrary to the small firms, particularly the large Route 128 firms had very low backward and forward linkages to the region. In total (weighted average of all 40 Boston firms in the survey) only 22% of all inputs were drawn from a 50 miles radius, whereas only 4% of total output was sold in the region.

31) Since the late 1980s considerable job losses occured in the once leading firms - DEC, Prime, Honeywell, Wang

It is only recently that the leading computer firms in Massachusetts have begun to try new strategies and to change their product structure and organisation more radically (Porter et al. 1991). DEC e.g. is moving towards network solutions, system integration and software development, and Prime has gone into the CAD/CAM market and formed an alliance with the Californian MIPS computer systems to get access to leading edge technolgies in hardware. Data General has split into two units, one responsible for the development of open systems, the other upgrading the proprietary system. The company has recently also introduced a new line of work stations, for which the firm applied a new distribution approach by entering into partnerships with a number of resellers familiar with the needs of specific markets. These develop software which they sell together with Data General work stations.

The question arises why Silicon Valley and Route 128 firms reacted collectively so differently in the 1980s. Possible explanations are:

* Route 128 firms are an older vintage of firms and thus are oriented to older types of products; due to technological and organisational rigidities they are somewhat constrained to stay in their specific market segment.

* Route 128 firms are "burdened" by the industrial history of the area. They rely more on a conservative business culture and on inherited management techniques, making them stick more to the hierarchical large firm model.

* The regional network of suppliers at the beginning of the 1980s in Silicon Valley was still in better shape and easier to revitalise compared to the one of Route 128.

However, the situation for the region as a whole is not as bleak as it looks from the perspective of the older minicomputer firms. Overall, the institutions and the networks for the formation of high-tech firms are still functioning although at a slower pace than in the past. There are still very dynamic segments emerging in the information technology cluster such as

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and Data General. Between 1985 and 1991 an estimated 14000 employees in the minicomputer industry in Massachusetts (about 1/3) had lost their jobs (Preer, 1992, p.7), but the employment reduction has continued since then. This has been reflected in a decline of total high-tech employment in Massachusetts: Harrison and Kluver (1989) have shown the dramatic change in the region's high- tech sector from an increase of 120000 jobs between 1973 to 1984 to a loss of 20000 from 1984 to 1987.

some newer computer firms (Stratus, Thinking Machines) [32] as well as software firms which expanded considerably in the 1980s [33]. Moreover, there are various other dynamic industries belonging to the "knowledge cluster" (universities, research, consulting), the "financial cluster" as well as the "health cluster" (Porter et al. 1991). A part of the latter is the newly emerging biotechnology industry.

3.3 Networks in the biotechnology industry

Industry background

Biotechnology, the commercialization of modern biology, is a very young industry [34]. Although major scientific progress such as the discovery of the structure of the DNA had occurred during the 1950s, it was not until the mid 1970s that the technology had advanced far enough to be commercialised. In 1992 there were about 1100 biotechnology companies in the US [35]. Initially "gene splicing" drew public attention; the true breakthrough, however, was the ability to make larger complex molecules ("proteins"), the basic chemical building block of life. The following features shape the structure and dynamics of the industry (see Burrill et al. 1989, Feinstein 1990, Nelson 1991 and Dibner 1991):

* The industry is still closely related to (university) research and companies are founded in response to scientific discoveries [36].

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32) Stratus, founded in 1980 in part by a former Data General employee, concentrates in fault-tolerant computer systems. Thinking Machines established in 1983 by a Harvard and a MIT PhD graduate, is the second-largest manufacturer of supercomputers in the US and had 10% of the world's base in 1990 (Porter 1991).

33) About 70% of the 800 software firms in Massachusetts were founded after 1980, and employment grew by 10.8% annually from 1980-1990 (Porter et al. 1991). The latest Guide to the Massachusetts Software Industry, published by the Massachusetts Computer Software Council (1992), counts as many as 1415 firms in the state.

34) Biotechnology companies are generally defined as those that " ... use biological processes to develop products for human health care, agriculture productivity, animal health, food safety and nutrition and industrial and environmental improvement" (Burrill and Lee, 1992). An early pioneer was Genentech, founded in 1976 in San Francisco.

35) Most of them are small companies; only about 150 large corporations have established major R&D efforts in biotechnology (Dibner 1991). Stock in about 225 companies is publicly traded (Burrill and Lee, 1992) .

36) As Lita Nelson (1991, p.41) states it: "For the biotechnology industry, and particularly that segment concerned with therapeutics, the university is the primary source of new product ideas. The typical new product concept

* The product development cycle is very long (3-8 years); consequently, only the older companies are now having products on the market. The long time lag is caused not just by the scientific explorations but also by a lengthy regulatory review process.

* The long and expensive product development cycle requires long term financing. Usually there are multiple rounds of financing and frequently support from larger companies involved.

* The industry, like pharmaceuticals, is strongly regulated: The Food and Drug Administration, the Department of Agriculure and the Environmental Protection Agency are critical regulatory bodies. In addition, cities and communities have created different regulatory environments,

Current dynamics of the industry arise from start-ups of small firms developing their products in close relation to universities or research facilities. However, capital and other requirements very often force small firms into alliances with large companies in pharmaceutical, medical or agricultural industries. Dibner and Bulluck (1992) observed about 1300 strategic alliances of US biotechnology firms, of which 55% were within the US and 45% with foreign partners, mainly European or Japanese companies. The general pattern is that the small firms provide the technology and the large firms contribute finance and market access as well as regulatory and production knowledge. The most frequent types of alliances were marketing (35%) and licencing agreements (25%) as well as research contracts (11%). In the late 1980s also alliances among the small firms became more common.

In addition, university linkages play an important role since 70% of US biotechnology companies maintain such relations (Dibner and Bulluck, 1992). These university links comprise a broad spectrum, from single patent licensing agreements and sponsored research to more complex research and development collaborations. The typical motives for companies to enter these links are early access to technology, staying up to date with scientific advances, access to special equipment or materials, access to intellectual property rights, or cost savings through the externalisation of development work (Nelson 1991).

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arises directly from a scientific finding: the scientist observes a new effect, isolates a new gene and/or protein, and then hypothesizes its function and its use in the human body." In this process, the road from 'pure science' to the vision of a product is unusually short, however, from there to a product on the market it is unusually long.

Biotechnology in Massachusetts

The state of Massachusetts ranks third after California and New York/New Jersey as locations for the biotechnology industry, about 10% of the companies in the US are located there. The industry started in the Cambridge/Boston area in the late 1970s with the foundation of BioGen (1978) and Genetics (1980). In 1992 there were already 130 companies with annual sales of $ 1,62 billion and an employment of about 13 000 (NAIOP, 1992). Still, most of them are quite small. Reflecting the region's strength in medical institutions, the companies are primarily engaged in therapeutics (41%) and diagnostics (39%), whereas just a few (8%) are in agriculture (Feinstein 1990).

Since most of the companies in Massachusetts are still early in the product development cycle, they are on average highly R&D intensive: 44% of the employment is in R&D, 31% in administration and only 24% in production. However, future employment growth is expected to be much stronger in manufacturing. Another consequence of the early development stage is low profitability: 2/3 of the companies have reported losses in 1990 (Feinstein 1990).

Local institutions have played a considerable role for the development of this industry in the region (see fig. 3)37. The major factor is the preeminence of its **research institutions**. Both Harvard and MIT have made major committments to molecular biology since the 1950s and have a number of Nobel laureates working in biological sciences. Both universities also have active licensing offices speeding up the commercialisation of scientific discoveries through licensing-help and through the support of start-ups [38]. Besides these two, other universities like Tufts and Worcester are active in this field.

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37) Fig. 3 is strongly based on interviews amongst others with Lita Nelson (MIT Technology Licensing Office), Skip Irving (United Office of Technology Transfer, Worcester), Ronald Baird (Worcester Polytechnic Institute, Fernando Quezada (President of the Biotechnology Center of Excellence Corporation, Boston), Mark Goldberg and Josef Carter (Massachusetts Biotechnology Research Institute), Gloria Doubleday (Commonwealth BioVentures Inc.), as well as on information from several Biotechnology firms.

38) About 1/2 of all 40 start-ups which the MIT licensing office supported since the mid 1980s were in biotechnology. A typical MIT start-up involves a PhD graduate, a faculty member and a venture capitalist. Sometimes also the university takes a small share of equity. In order to optimise communication to MIT researchers the new firms often try to locate close to MIT (interview with Lita Nelson, Dec. 1992).

In addition, the extensive **medical community** makes significant contributions. The Massachusetts General Hospital is a leading medical research center in biotechnology. Currently it maintains research agreements with several major health care firms.[39] The Dana-Farber Cancer Institute provided the early research for ImmunoGen, a biotechnology company developing cancer fighting monoclonal antibodies (Feinstein 1990) [40].

The strong role of university and medical research is **reflected in the location pattern** of biotechnology firms. 30% are located in Cambridge (close to MIT and Harvard) and about 10% in Boston, primarily near the teaching hospitals (Feinstein 1990). A new biotechnology focus is emerging in the Worcester Research Park (70 km west of Boston), which currently has about 14% of the firms. In Feinstein's (1990) study 84% of the companies reported that proximity to a university was an important location criteria and 35% stated it as their first priority in site selection.

Due to the large and long-run capital requirements, **venture capitalists** together with other finance sources are important actors for the development of the industry. Although only a share of the start-ups and new projects are financed locally [41], the large number of venture capitalists in the area is certainly a favouring factor. Finally, specialised **business services** such as lawyers, accountants, banks and architects, familiar with the needs of the biotechnology industry, are supporting the growing industry.

State and local governments have played a smaller role in development of this industry in Massachusetts than in other states such as North Carolina or Maryland. Most firms starting in the past decade did so without much government support. Local and state institutions, howe-

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39) Including Hoechst for $68 million, Shisheide for $85 million and Bristol-Myers/Squibb for $37 million.

40) Active in biomedical research are also the Childrens's Hospital, Beth Israel Hospital, Brigham and Womens's Hospital and others which are affiliated with Harvard Medical School (NAIOP, 1992. p. A6). Rosegrant and Lampe find that "many of the more than forty-five biotechnology firms in the Cambridge and Boston area either had their roots in the local medical establishment or maintain direct links with the medical reserach community" (1992, p. 19).

41) An estimation by Lita Nelson from the MIT licensing office is a local venture capital share of about 1/2 for the MIT start-ups. The rest is financed by venture capitalists from New York as well as the West Coast, the other major centers of venture capital in the US.

ver, played a stronger role in the formation of the biotechnology research park in Worcester[42].

An important factor for the development of the industries is the "**regulatory environment**" of an area as well as the public opinion towards it. Both factors seem to be favourable in Massachusetts. A high percentage of firms expressed satisfaction with the local regulations in the study by Feinstein (1990), whereby not necessarily an absence of rules, but their longrun stability is sought by the firms. The public opinion towards the industry can also be a relevant location factor as the recent move of a large BASF R&D unit from Germany to Worcester/-Massachusetts has demonstrated. BASF stated that by moving to Massachusetts it was avoiding resistance against the industry in its home country.

However, like the industry in general, the biotechnology firms of Massachusetts are nut just embedded into local and regional networks, they quite rapidly get interlinked into national and international ones. Financial and production requirements as well as the need to gain access to (foreign) regulatory knowledge and markets force firms into **alliances** and partly **mergers** with large U.S. and international firms. Firms like Genetics Institute, Cambridge Biotech or Biogen have each entered into several of these alliances, covering R&D joint ventures, R&D contracts, licensing agreements, as well as manufacturing and marketing agreements (see. fig. 4 for selected Massachusetts firms). These alliances are not without ambivalence, however, since local industry is partly selling away its downstream activities and expansion opportunities. It is expected that much of the manufacturing, marketing and administration of the biotechnology industry will locate outside the region (Brunetta, 1992).

4) Conclusions

The following conclusions may be derived from the analysis. (1) Local and regional institu-

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42) Interviews with Fernando Quezada (Biotechnology Center of Excellence Corporation), Josef Carter, Abraham Haddad and Mark Goldberg (Massachusetts Biotechnology Research Institute) and Tom Anrews (Worcester Biotechnology Research Park) in March 1993. See also Gorer (1991).

tions matter for the development of high-technology firms. Relevant institutions and actors in general include research universities, technology transfer institutions, venture capital firms and specialised business services as well as suppliers and customers. Critical is the interaction and the networking of such organisations, not just their mere existence.

(2) Networks differ between industries as the comparison of the computer and biotechnology industry shows. The computer industry relies less on university research and has consequently few research collaborations with universities. Instead, computer firms rely more on interfirm linkages. They partly form complex networks with suppliers of electronic and mechanical components as well as of software, linkages which often include collaborative development. Biotechnology, being at an early stage, is still very R&D-intensive and consequently relies much more on university or hospital research (frequently local links) as well as on venture capital firms and other financially strong partners. Due to these features and particularly the lack of vertical linkages within the region the biotechnology industry currently does not achieve a similar spectacular growth as the computer and electronic industry did in the 1960s.

(3) Networks change during the life-cycle of an industry. In general, local and regional networks are more important for the formation and early growth period. As the industry matures not just the markets but also the supplier and collaborative linkages become international and global. However, this is not a deterministic pattern since there are different models of industrial organisation. Regional networks may still be relevant also in mature industries, as the computer firms in Silicon Valley have demonstrated in the 1980s. In contrast to Route 128 firms, they achieved competitive advantages by relying on regional suppliers and collaborators and thereby reduced cost and improved their innovative performance as well as product quality. On the other hand, the biotechnology industry shows that not just local university and medical links, but also international alliances, may be necessary already at an early stage. This fact results from the specificities of the industry such as the long product development cycle and the high and long-term capital demand. The strong link to university and medical research may get weaker in the future, once production becomes more important.

(4) High-tech industries draw on very specific knowledge-bases, such as research in particular technological fields or highly specialised suppliers of components or services. There are usually only few regions in a country where such "localisation economies" for certain industries exist and these can prosper. Consequently, specific high-tech industries are strongly concentrated in space. In larger knowledge-based economies such as the Greater Boston region, relevant institutions and networks in part are also of a "generic" nature, allowing the region to diversifiy and to develop new industries. Universities and educational institutions providing highly trained labor, as well as venture capitalists and business services contribute to an environment which supports the development of high-technology firms in general. The formation of the biotechnology industry in the Boston area in the 1980s was partly supported by the "inherited" network, namely the same institutions which had helped to start and develop Route 128.

(5) Which **policy conclusions** can be derived? The rather special conditions and networks which allow high-tech industries to prosper reduce the possibility to grow those industries at many locations, although currently many regions around the world are trying to do this. "Environments" for high-tech industries cannot easily be "created" when important preconditions are lacking. Only few regions have such features and, as the examples of Boston and other high-tech regions (Silicon Valley, Research Triangle Park in North Carolina) show, it takes quite a long time from the early beginnings to a dynamic selfsustaining development.

In general, policies to stimulate technology-based development in a region should not aim at the currently "fashionable" high-tech industries. For these the respective region may not have the preconditions and, in addition, there is a strong interregional and international competition for firms and markets. Instead, regions should focus on their existing industry and knowledge base and improve the innovative performance of these industries by strengthening networks between firms and relevant institutions. Networking, however, should not be confined to the region but include firms and institutions in other regions and foreign countries. It is through this insertion into local/regional networks as well as into distant networks that technology-based firms are able to stay competititve in the long run.

REFERENCES

Aldrich, H.E., 1979, Organizations and Environment. Englewood Cliffs.

Alic, J., 1990, Cooperation in R&D, Technovation 10/5, pp. 319-332.

Aydalot, Ph. and D. Keeble, 1988, eds., High Technology Industry and Innovative Environments: The European Experience. London, Routledge.

Bathelt, H., 1991, Employment changes and input-output linkages in key technology industries: A comparative analysis. Regional Studies, Vol 25.1, pp. 31-43.

Bank of Boston, 1989, MIT - Growing business for the future. Boston.

Bergman, E., G. Maier and F. Tödtling, 1991, eds., Regions Reconsidered: Networks, Innovation, and Local Development in Industrialized Countries. London, Cassel.

Brunetta, L., 1992, Biotech. Regional Review, Boston/Massachusetts, Summer 1992.

Burill, G. and Ernst & Young High Technology Group. 1989, Biotech 90: Into the next decade.

Burill G. and K. Lee, 1992, Biotech 1993: Accelerating Commercialisaton. Ernst & Young High Technology Group.

Camagni, R., 1991, Space, networks and technical change: An evolutionary approach. In: Camagni, R., (ed.), Innovation Networks, London, Belhaven Press.

Cooke, Ph. and K. Morgan, 1991, The network paradigm - New departers in corporate & regional development. Regional Industrial Research Report, No. 8, Cardiff.

DeBresson C. and R. Walker, eds., 1991, Network of Innovators, Special Edition of Research Policy, Vol. 20, No. 5, North Holland.

Dibner, M.D., 1991, Tracking trends in U.S. Biotechnology. Biotechnology, Vol. 9, Dec. 1991, pp. 1334-1337.

Dibner, M.D. and J.A. Bulluck, 1992, U.S./European Strategic Alliances in Biotechnology. Biotech Forum Europe, Vol. 9., No. 10.

Dorfman, N. S., 1983, Route 128: The development of a regional high technology economy. Research Policy, 12, pp. 310-333.

Ewers H.J. and J. Allesch, 1990, Innovation and Regional Development - Strategies, Instruments and Policy Coordination. Walter de Gruyter, Berlin, New York.

Feinstein, P., 1990, An assessment of the Massachusetts biotechnology industry, Report to the Massachusetts Center of Excellence Corporation, Boston.

Ferguson, R. and H. L. Ladd, 1988, Massachusetts. In: R. S. Fosler, ed., The New Economic Role of American States - Strategies in a Competitive World Economy. Oxford University Press, New York / Oxford.

Florida, R., D.F. Smith Jr and E. Sechoka, 1991, Regional patterns of venture capital investment. In: M.B. Green, ed., Venture Capital - International Comparisons. Routledge, London/New York.

Freeman, C., 1991, Networks of innovators: A synthesis of research issues. Research Policy. Vol. 20, No. 5, pp. 499-514, North Holland.

Gomes-Casseres, B., 1992, Computers: Alliances and industry evolution. Harvard Business School, Cambridge, Massachusetts, Mimeo.

Gordon, R., 1991, Innovation, industrial networks and high technology regions. In: R. Camagni, ed., Innovation networks: spatial perspectives. Belhaven Press, London/New York.

Gorer, P., 1991, Public/private collaboration in support of Biotechnology development: The Massachusetts Biotechnology Research Park. Prepared for the Biotechnology Center of Excellence Corporation, Boston.

Green, M.B., 1991, Preferences for US venture capital investment 1979-1988. In: M.B. Green, ed., Venture Capital - International Comparisons. Routledge, London/New York.

Hagedoorn, J. and J. Schankenraad, 1990, Strategic partnering and technological cooperation. In: Dankbaar, B, J Groenewegen and H Schenk, eds., Perspectives in Industrial Organization. Dordrecht/Boston/London, Kluwer.

Hagedoorn, J. and J. Schankenraad, 1992, Leading companies and networks of strategic alliances in information technologies. Research Policy 21, 163-190.

Hakansson, H., ed., 1987, Industrial Technological Development: A Network Approach. London, Croom Helm.

Harrison, B. and J. Kluver, 1989, Deindustrialization and regional restructuring in Massachusetts. In: L. Rodwin and H. Sazanami, eds., Deindustrialization and Regional Economic Transformaiton - The Experiences of the United States. Unwin Hyman, Boston.

Luger, M. and H. Goldstein, 1990, Technology in the Garden: Research Parks and Regional Economic Development. Chapel Hill & London, The University of North Carolina Press.

Lundvall, B.A., 1988, Innovation as an interactive process: from user-producer interaction to the national system of innovation. In: Dosi, G., Ch. Freemam, R. Nelson, G. Silverberg, and L. Soete, eds., Technical Change and Economic Theory. London, Pinter.

Malecki, E., 1990, New firm formation in the USA: Corporate structure, venture capital, and local development. Entrepreneurship & Regional Development, 2, pp. 247-265.

Malecki, E., 1991, Technology and Economic Development - The dynamics of local, regional and national change. Longman, Scientific & Technical, Essex.

Maillat, D., 1991, The innovation process and the role of the mileu. In: Bergman, E., G. Maier and F. Tödtling, 1991, eds., Regions Reconsidered: Networks, Innovation, and Local Development in Industrialized Countries. London, Cassel.

Maillat, D., Michel Quevit and L. Senn, 1993, Reseaux d'innovation et milieux innovateurs: un pari pour le development regional. EDES, Neuchatel.

Miller, M. and M. Coté, 1987, Growing the Next Silicon Valley - A Guide for Successful Regional Planning. Lexington Books, Lexington/Massachusetts.

Mowery, D.C. and N. Rosenberg, 1989, Technology and the Pursuit of Economic Growth, Cambridge University Press, Cambridge.

NAIOP Association for Commercial Real Estate and Forest City Development University Park at MIT, 1992, Biotechnology Industry Needs in the 1990's - Enhancing Massachusetts' Competitive Edge. Newton/Cambridge.

Nelson, L., 1991, The lifeblood of biotechnology: university-industry technology transfer. In R.D. Ono, ed., The Business of Biotechnology - From the Bench to the Street. Butterworth-Heinemann, Boston / London.

Pisano, G. P., 1991, The governance of innovation: Vertical integration and collaborative arrangements in the biotechnology industry. Research Policy 20, pp. 237-249.

Porter, M., 1990, The Competitiveness of Nations. The Free Press, New York.

Porter, M. in collaboration with Monitor Company, Inc., 1991, The Competitve Advantage of Massachusetts, Report, Harvard Business School, Cambridge.

Preer, R., 1992, The Emergence of Technopolis. Knowledge-intensive Technologies and Regional Development. Praeger Publishers, New York.

Premus, R., 1990, Technology transfer and regional policy. In: R. Cappellin and P. Nijkamp, eds., The Spatial Context of Technological Development. Avebury, Aldershot.

Pyke, F. and W. Sengenberger, eds., 1992, Industrial Districts and Local Economic Regeneration. International Institute for Labor Studies, Geneva.

Roberts, E. B., 1991, Entrepreneurschip in High Technology - Lessons from MIT and Beyond. Oxford University Press, Oxford / New York.

Rosegrant, S. and D. R. Lampe, 1992, Route 128 - Lessons from Boston's High Tech Community. Basic Books, Harper-CollinsPublishers, U.S.

Rothwell, R., 1991, External networking and innovation in small and mediu-sized manufacturing firms in Europe. Technovation, 11/2, pp. 93-112.

Sabel, Ch., 1989, Flexible specialisation and the reemergence of regional economies. In: P. Hirst and J. Zeitlin, eds., Reversing Industrial Decline. St. Martin's Press, New York.

Sabel, Ch., 1992, Studied trust: buyilding new forms of cooperation in a volatile economy. In: F. Pyke and W. Sengenberger, eds., Industrial Districts and Local Economic Regeneration. International Institute for Labor Studies, Geneva.

Saxenian, A., 1991, The origins and dynamics of production networks in Silicaon Valley. Research Policy, Vol. 20 No. 5, pp. 423-437.

Saxenian, A. L., 1992, Regional Networks: Industrial Adaption in Silicon Valley and Route 128. Department of City and Regional Planning, University of California, Berkeley.

Scherer, F. M., 1992, International High-Technology Competition. Harvard University Press, Cambridge/Mass., London.

Schmandt, J. and R. Wilson, eds., 1990, Growth Policy in the Age of High Technology: The Role of Regions and States. London/Massachusets, Unwin Hyman.

Schmitz, H., 1992, Industrial districts: Model and reality in Baden-Württemberg, Germany. In: Pyke, F. and W. Sengenberger, eds., Industrial Districts and Local Economic Regeneration. International Institute for Labor Studies, Geneva.

Schoonhoven, C. and K. Eisenhardt, 1992, Regions as industrial incubators of technology-based ventures. In: E. Mills and J. MacDonald (eds.), Sources of Metropolitan Growth, New Jersey, Center for Urban Policy Research.

Scott, A.J., 1987, Flexible production systems and regional development: The rise of new industrial spaces in North America and Western Europe. Journal of Urban and Regional Research, Vol. 12/2, S. 171-185.

Scott, A., 1992, The role of large producers in industrial districts: A case study of high technology systems houses in Southern California. Regional Studies, Vol. 26, pp. 265-275.

Shimshoni, D., 1966, Aspects of Scientific Entrepreneurship, PhD. Dissertation, Harvard University, Cambridge/Massachusetts.

Sternberg, R., 1988, Technologie- und Gründerzentren als Instrument kommunaler Wirtschaftförderung. Dortmund.

Stöhr, W., 1987, Territorial Innovation Complexes. Papers of the Regional Science Association, Vol. 59, S. 29-44.

Storper and Harrison, 1991, Flexibility, hierarchy and regional development: The changing structure of industrial production systems and their forms of governance in the 1990's. Research Policy, Vol. 20, No. 5, pp. 407-422. North Holland.

Storper, M., 1992, The limits to globalization: Technology districts and international trade. Economic Geography, pp. 60-93.

Tödtling, F., 1992, The uneven lanscape of innovation poles - Local embeddedness and global networks. IIR-Discussion 46, University of Economics Vienna.

Utterback, J.M., 1979, The dynamics of product and process innovation in industry. In: Hill Ch.t. and J.M. Utterback, eds., Technological Innovation for a Dynamic Economy. New York, Pergamon Press.

Vernon, R., 1966, International investment and international trade in the produce cycle. Quarterly Journal of Economics, 1966/2, S. 190-207.

Vet, J. M. and A. Scott, 1992, The Southern Californian medical device industry: Innovation, new firm formation, and location. Research Policy 21, 145-161.

von Hippel, E., 1987, The Sources of Innovation. Oxford University Press.

Williamson, O., 1985, The Economic Institutions of Capitalism. The Free Press, New York.

Fig. 1: The high-technology firm and its environment

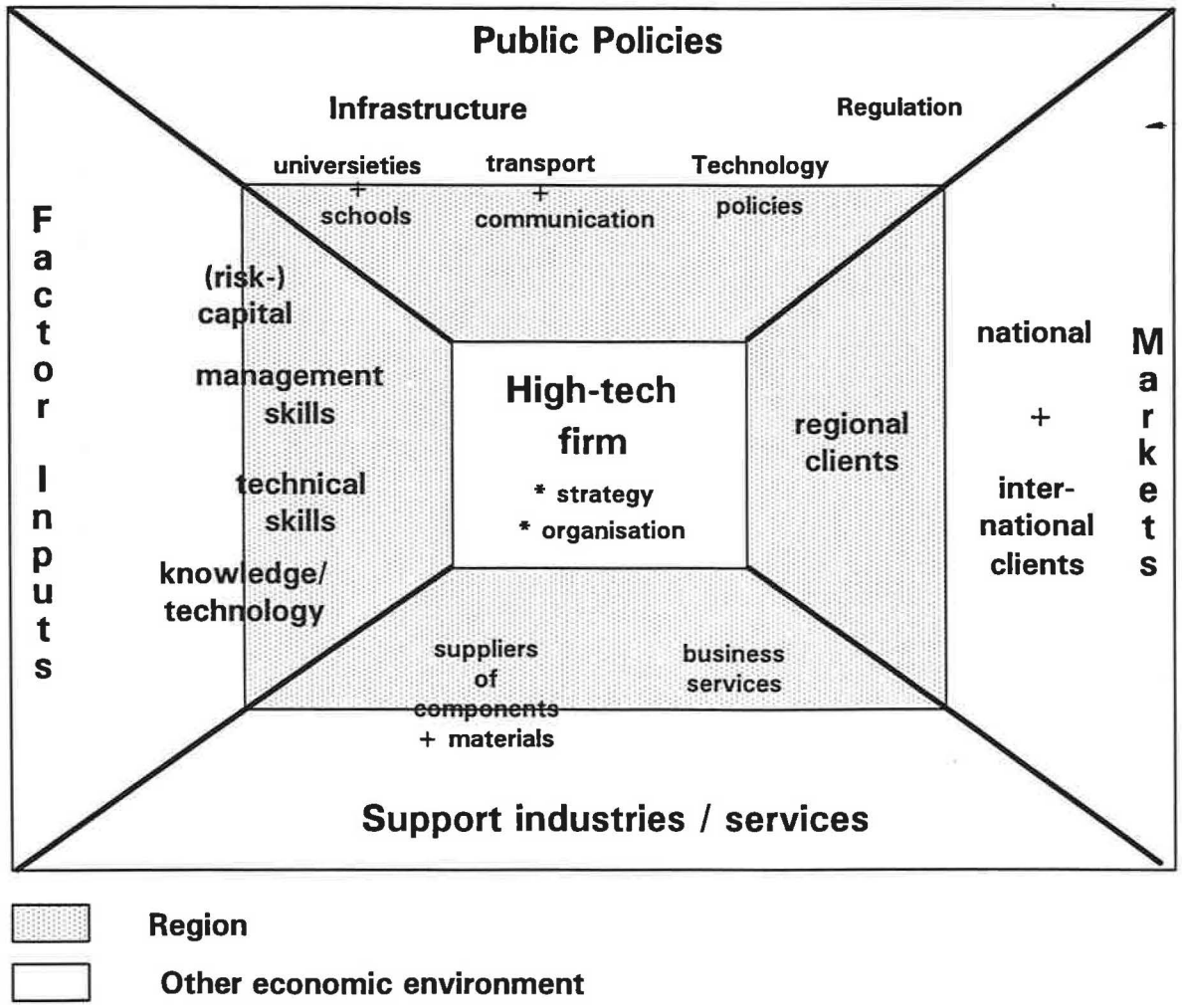
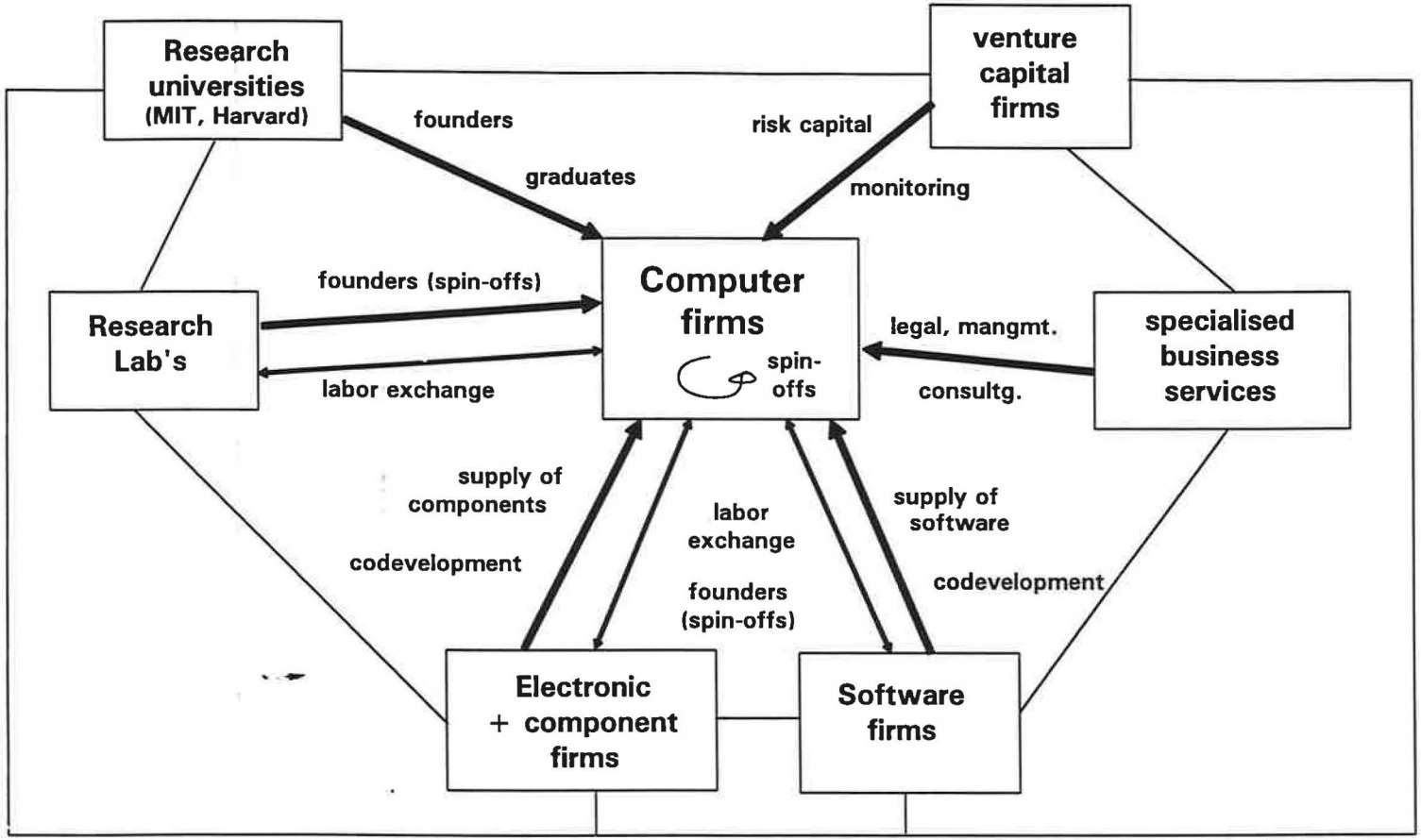
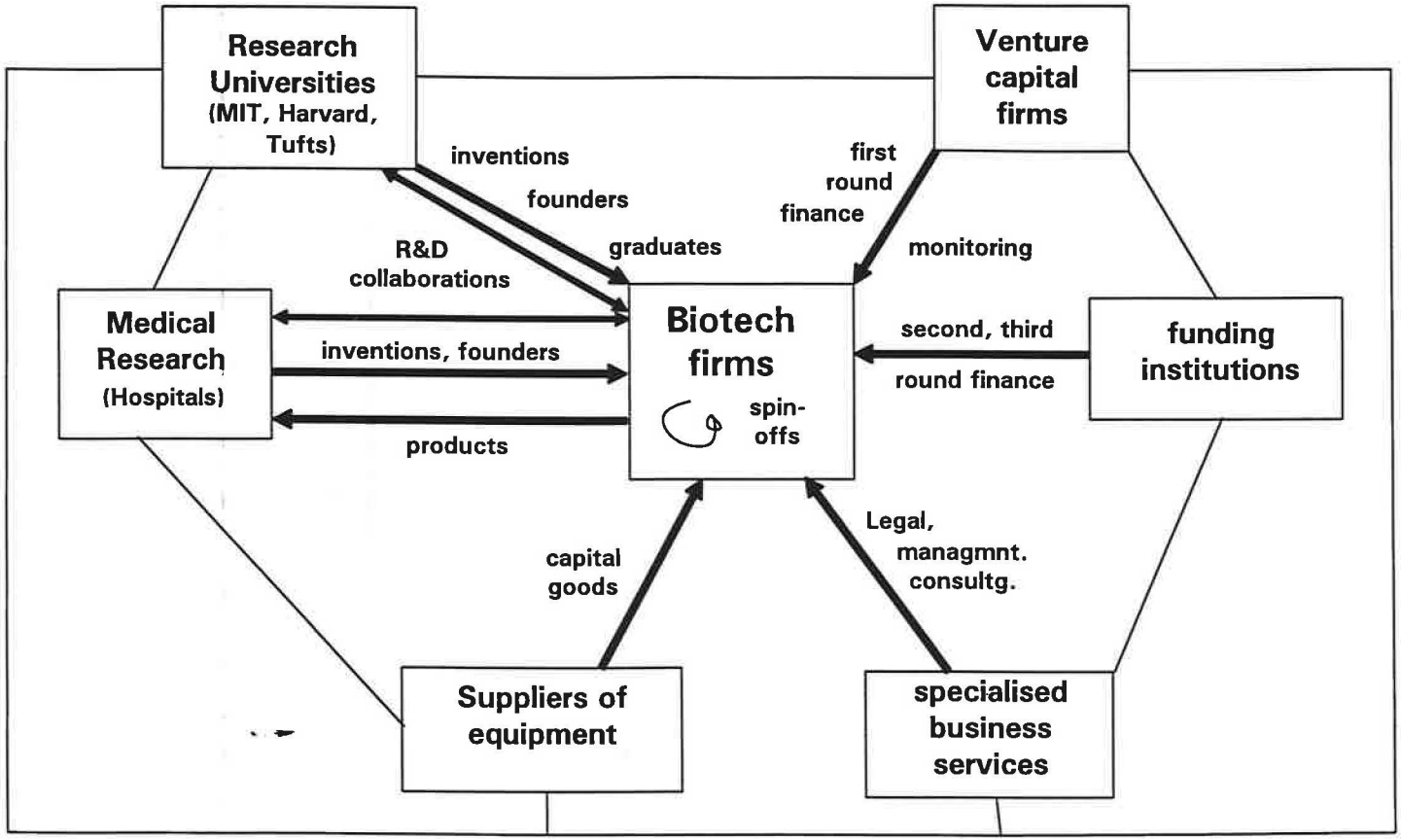


Fig. 2: Regional network of the computer industry (formation of Route 128 - stylised)



Note: Federal links (government contracts) as well as US and international alliances are not taken into account

Fig. 3: Regional network of the biotech industry in Massachusetts (stylised)



Note: US and international alliances not taken into account

Fig. 4: Strategic Alliances of Massachusets Biotechnology Firms (after Brunetta 1992)