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Technological change and regional restructuring in Boston's Route 128 area

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1 Introduction: Route 128 and the ill-fated debate on industrial districts

During the 1980s and early 1990s, the importance of small firm growth and industrial districts in Italy became the focus of a large number of regional development studies. According to this literature, successful industrial districts are characterized by intensive cooperation and market producer-user interaction between small and medium-sized, flexibly specialized firms (Piore and Sabel, 1984; Scott, 1988). In addition, specialized local labor markets develop which are complemented by a variety of supportive institutions and a tradition of collaboration based on trust relations (Amin and Robins, 1990; Amin and Thrift, 1995). It has also been emphasized that industrial districts are deeply embedded into the socio-institutional structures within their particular regions (Grabher, 1993).

Many case studies have attempted to find evidence that the regional patterns identified in Italy are a reflection of a general trend in industrial development rather than just being historical exceptions. Silicon Valley, which is focused on high technology production, has been identified as being one such production complex similar to those in Italy (see, for instance, Hayter, 1997). However, some remarkable differences do exist in the institutional context of this region, as well as its particular social division of labor (Markusen, 1996). Even though critics, such as Amin and Robins (1990), emphasized quite early that the Italian experience could not easily be applied to other socio-cultural settings, many studies have classified other high technology regions in the U.S. as being industrial districts, such as Boston's Route 128 area.

Too much attention has been paid to the performance of small and medium-sized firms and the regional level of industrial production in the ill-fated debate regarding industrial districts (Martinelli and Schoenberger, 1991). Harrison (1997) has provided substantial evidence that large firms continue to dominate the global economy. This does not, however, imply that a de-territorialization of economic growth is necessarily taking place as globalization tendencies continue (Storper, 1997; Maskell and Malmberg, 1998). In the case of Boston, it has been misleading to define its regional economy as being an industrial district. Neither have small and medium-sized firms been decisive in the development of the Route 128 area nor has the region developed a tradition of close communication between vertically-disintegrated firms (Dorfman, 1983; Bathelt, 1991a). Saxenian (1994) found that Boston's economy contrasted sharply with that of an industrial district. Specifically, the region has been dominated by large, vertically-integrated high technology firms which are reliant on proprietary technologies and autarkic firm structures.

Several studies have tried to compare the development of the Route 128 region to Silicon Valley. These studies have shown that both regions developed into major

agglomerations of high technology industries in the post-World War II period. Due to their different traditions, structures and practices, Silicon Valley and Route 128 have followed divergent development paths which have resulted in a different regional specialization (Dorfman, 1983; Saxenian, 1985; Kenney and von Burg, 1999). In the mid 1970s, both regions were almost equally important in terms of the size of their high technology sectors. Since then, however, Silicon Valley has become more important and has now the largest agglomeration of leading-edge technologies in the U.S. (Saxenian, 1994).

Saxenian (1994) argues that the superior performance of high technology industries in Silicon Valley over those in Boston is based on different organizational patterns and manufacturing cultures which are embedded in those socio-institutional traditions which are particular to each region. Despite the fact that Saxenian (1994) has been criticized for basing her conclusions on weak empirical research (i.e. Harrison, 1997; Markusen, 1998), she offers a convincing explanation as to why the development paths of both regions have differed.[1] Saxenian's (1994) study does not, however, identify which structures and processes have enabled both regions to overcome economic crises. In the case of the Boston economy, high technology industries have proven that they are capable of readjusting and rejuvenating their product and process structures in such a way that further innovation and growth is stimulated. This is also exemplified by the region's recent economic development.

In the late 1980s, Boston experienced an economic decline when the minicomputer industry lost its competitive basis and defense expenditures were drastically reduced. The number of high technology manufacturing jobs decreased by more than 45,000 between 1987 and 1995. By the mid 1990s, however, the regional economy began to recover. The rapidly growing software sector compensated for some of the losses experienced in manufacturing. In this paper, I aim to identify the forces behind this economic recovery. I will investigate whether high technology firms have uncovered new ways to overcome the crisis and the extent to which they have given up their focus on self-reliance and autarkic structures. The empirical findings will also be discussed in the context of the recent debate about the importance of regional competence and collective learning (Storper, 1997; Maskell and Malmberg, 1998). There is a growing body of literature which suggests that some regional economies

[1] Kenney and von Burg (1999) do not agree with this explanation. In contrast, they emphasize the importance of technological trajectories in understanding the divergent economic growth patterns of Silicon Valley and Route 128. They argue that Silicon Valley exhibited a higher growth rate than the Boston region because the technological development path of its dominant semiconductor industry was superior to that of Boston's leading sector (i.e. the minicomputer industry). According to Kenney and von Burg (1999), Silicon Valley's semiconductor industry offered greater opportunities for further technological developments and cross-sectoral applications than Boston's minicomputer industry. This allowed for a stronger growth performance of Silicon Valley over the Boston region. Even though Kenney and von Burg (1999) openly reject the idea of technological determinism, their arguments could be actually interpreted to be in support of it (see, for a criticism, Saxenian, 1999).

can develop into learning economies which are based on intra-regional production linkages, interactive technological learning processes, flexibility and proximity (Storper, 1992; Lundvall and Johnson, 1994; Gregersen and Johnson, 1997).

In the next section of this paper, I will discuss some of the theoretical issues regarding localized learning processes, learning economies and learning regions (see, also, Bathelt, 1999). I will then describe the methodology used. What follows is a brief overview of how Boston's economy has specialized in high technology production. The main part of the paper will then focus on recent trends in Boston's high technology industries. It will be shown that the high technology economy consists of different subsectors which are not tied to a single technological development path. The various subsectors are, at least partially, dependent on different forces and unrelated processes. There is, however, tentative evidence which suggests that cooperative behavior and collective learning in supplier-producer-user relations have become important factors in securing reproductivity in the regional structure. The importance of these trends will be discussed in the conclusions.

2 Region-specific assets, localized competencies and regional specialization

In his seminal work on production and trade patterns, Krugman (1991) emphasizes the importance of the regional (subnational) level for industrial concentration and specialization processes. His work on local specialization tendencies draws on Marshall's (1927) classic economic analysis of industry localization. According to Krugman (1991), local specialization is a product of three factors. First, the existence of both a large pool of and a high demand for specialized labor in a region increases its attractiveness for other workers and firms in that particular area of specialization. Second, an agglomeration of specialized suppliers develops over time because suppliers tend to choose their locations close to major markets. Through this, they can gain economies of scale and distribute large parts of their production at low cost (i.e. transportation cost). Third, technological spillover effects are a result of intensive local information exchange. They are a consequence of a particular 'industrial atmosphere' which stimulates the creation and dissemination of knowledge.

Krugman (1991) views technological spillover as being the least important of the three factors because, according to his analysis, such effects tend to be limited to high technology industries. In this respect, his evaluation differs substantially from Scott's (1988) and Storper and Walker's (1989) investigation of agglomeration tendencies. Krugman's (1991) emphasis on increasing returns and transportation costs fails to provide a deeper understanding of the role of communication and adjustment processes between firms in a value chain. Such inter-firm linkages are not restricted to high technology industries. A growing body of literature suggests that

complex innovation processes rely heavily on intensive supplier-producer-user interaction and corresponding learning processes (Lundvall, 1988; Lundvall and Johnson, 1994; Gertler, 1997).

In this context, Storper (1992) emphasizes the importance of conventions and relations in technological learning processes (see, also, Morgan, 1997). Storper (1997) argues that the goals of complex innovation processes are not pre-determined. They become defined through actions when the process is already underway. As a result of reflexive behavior, goals are constantly being redefined according to new information about the success of previous actions. Dynamic, interactive innovation processes rely on relations between particular people and/or the existence of conventions as expressed in accepted norms, rules and practices. Lundvall and Johnson (1994) have used the notion of the 'learning economy' to describe such innovative behavior.[2] Conventions can be defined as social arrangements (e.g. with respect to the technologies used and the resources to be mobilized) which allow firms and people to cooperate in particular projects (Boyer and Orléan, 1992). They are especially important in the areas of supplier and customer relations, information exchange between firms, intra-firm communication processes, labor market relations and linkages with institutions (Storper, 1997).

A technological development path is the result of ongoing communication and adjustment processes between those people and firms involved (see, for example, Morgan, 1997; Asheim, 1998; Bathelt, 1999). Relations and conventions are also localized because they are cumulative in nature and involve the exchange of non-cosmopolitan knowledge.[3] In other words, they are bound to particular people and firms and cannot readily be transferred to other places (Storper, 1997). Relations and conventions are selective in that they define which people and firms can participate in an innovation process. They become region-specific assets and form the basis for further concentration and specialization of economic activities. Through this, the region becomes a catalyst for the development of a learning economy (Lundvall and Johnson, 1994; Gregersen and Johnson, 1997).[4] As a consequence, territorial production systems (i.e. technology districts) can develop which are characterized by networks of small and medium-sized, vertically-disintegrated firms (or by more or less

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[2] The learning economy functions as an organized market (Lundvall and Johnson, 1994). It differs from a pure market, in that it allows for efficient communication linkages between producers and users. As opposed to a pure hierarchy, it generates diversity in network relations.

[3] Boyer and Orléan (1994) argue that a change of conventions is not possible without social regulation because once a convention is in place non-conformist behavior would be penalized. This implies that spatial proximity between the respective actors may play an important role when facilitating conventions and their changes.

[4] A similar notion which is used in the context of regional and urban planning projects is that of the 'learning region' (e.g. Hassink, 1997; Morgan, 1997). Unfortunately, this notion is often not precisely defined. The theoretical basis as discussed here is either neglected or transferred to the planning level without rigor.

hierarchical linkage systems of large, vertically-integrated firms). Within these technology districts, collective learning, flexibility and proximity are closely interrelated and stimulate one another (Storper, 1992). Information and knowledge is, thus, often created locally before it becomes available in other regions and countries (Fritsch et al., 1998).

The importance of learning processes in a local context has also been highlighted by Maskell and Malmberg (1998). They argue that a firm's competitiveness depends on a unique set of competencies and its ability to develop them further through continuous learning processes. If such firm-specific competencies are based on localized capabilities (such as specialized resources and skills and shared trust, norms, routines, traditions and other local institutional structures), a regional competitive advantage will result.[5] Due to the evolutionary character of knowledge-generation, firms and regions with the most sophisticated skill levels, know-how and research activities have the best opportunities for further knowledge-creation. This attracts specialized economic activities to that particular region and stimulates cumulative regional growth (see, also, Morgan, 1997).

According to Maskell and Malmberg (1998), this may enhance regional specialization and concentration which, in turn, serves to strengthen the existing localized capabilities.[6] Initially, newly created knowledge is, at least partially, tacit in that it is specific to those people who learn it and those places and environments where the learning processes take place. The tacit knowledge-base of a region can be viewed as a localized capability which becomes partially ubiquitous through codification. In order to keep this tacit knowledge-base as a source of competitiveness, it has to be constantly renewed or exchanged through routes that do not allow for its wide geographical diffusion. This requires shared trust between firms; an element which is most likely to develop through face-to-face contact over short distances within a region.

In the remainder of this paper, I will relate my empirical findings to this discussion about regional learning, specialization and competitiveness. The question of the degree to which interactive learning processes, collective action and the existence of localized capabilities have stimulated restructuring processes in the Boston region will be addressed.

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[5] Supplier-producer-user interactions in the learning economy are not exclusively based on mutual trust and loyalty. They also encompass elements of power and hierarchy which affect the general directions of innovation processes (Lundvall and Johnson, 1994).

[6] According to Maskell and Malmberg (1998), globalization processes tend to weaken such regional contexts and threaten the competitiveness of the respective firms because they serve to make some localized capabilities (such as state-of-the-art technologies and organizational designs) more ubiquitous; that is, available at the same cost in many world regions. A similar process that is seen to undermine the competitiveness of a firm or region is the codification of tacit knowledge.

3 Methodology

This study is a product of ongoing research which has been conducted for more than 10 years, starting in 1987. This includes research trips to the Boston region in 1988 and 1998. During these trips, I was able to do a survey of high technology firms to supplement my intensive literature research of the Boston region. Overall, more than 80 personal interviews with executives and representatives of high technology firms, as well as planners, venture capital experts, members of industry associations, specialized service providers and people from other institutions were conducted. For this, relevant sectors and communities for inclusion into the study had to be defined and potential firms for interviews identified. The goal of providing a better understanding of the processes and practices which have shaped the nature of industrial production and the dynamics of the social division of labor in the Boston region has formed the basis for my research. The questions put forth have particularly focused on changes which have occurred in the product and process structure of high technology firms, the nature and intensity of their supplier and customer interaction and the ways in which regional assets are being used to reproduce the high technology economy.

The list of high technology industries included in this study was based on definitions used by Markusen et al. (1986), Bathelt (1990), Saxenian (1994) and Sternberg (1995).[7] The following SIC groups were included into the high technology definition used: drugs (SIC 283), computer and office equipment (SIC 357), household audio and video equipment (SIC 365), communications equipment (SIC 366), electronic components and accessories (SIC 367), aircraft and parts (SIC 372), guided missiles and space vehicles and parts (SIC 376), instruments and related products (SIC 38) and computer and data processing services (SIC 737).

The Boston or Route 128 region was defined here as consisting of the 4 counties of Essex, Middlesex, Norfolk and Suffolk (figure 1).[8] Of these counties, Middlesex is the most important in terms of the number of individuals employed in high technology industries. Middlesex accounted for 62% of the high technology labor force of the region in 1995 (U.S. Department of Commerce, 1997). The regional employment shares of Essex, Norfolk and Suffolk county were considerably lower with 16%, 17% and 5%, respectively.

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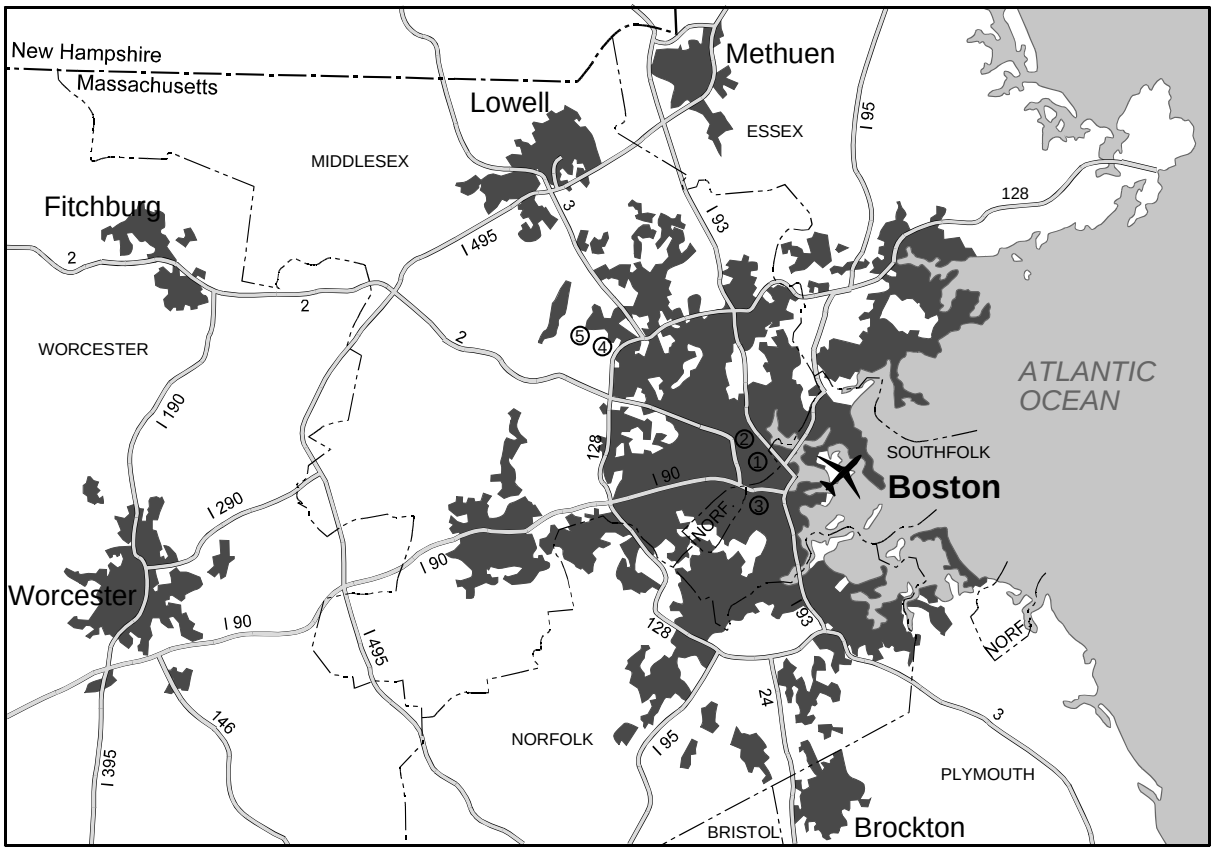
[7] In contrast to my earlier work (e.g. Bathelt 1991a), I have also included software production into this definition because of a trend in the industry to differentiate products through software instead of hardware adjustments.

[8] This regional definition includes a larger area than that of Greater Boston, which has sometimes been used in similar studies. The Greater Boston area includes the cities of Boston and Cambridge and a 15 to 30-mile ring of communities around Boston (see, for example, Bathelt, 1990).

Figure 1. The Boston Region



Logan International Airport

① Massachusetts Institute of Technology (MIT)
② Harvard University
③ Northeastern University
④ Lincoln Laboratories des MIT
⑤ Hanscom Field Air Force Base

My 1988 sample of high technology firms had focused on establishments located in the Middlesex and Suffolk counties. The survey consisted of 40 interviews with executives, manufacturing directors and other leading managers of local high technology firms. The response rate was 89% (Bathelt, 1991b). The 1998 sample was restricted to high technology establishments located in Middlesex county. In this survey, a smaller number of firms were chosen for intensive case studies. Of 19 firms which were selected from a manufacturing directory (Manufacturers' News, Inc., 1997) to participate in the survey, 12 (63%) agreed to an interview and on-site visit. One could argue that 12 firms are not enough for a representative analysis of industrial change in the Boston region. Such an investigation does, however, provide a starting point to identify some important trends. The establishments included in the study are located in Bedford, Burlington, Lexington, Marlborough, Maynard, Waltham, Wilmington and Woburn (figure 1; figure 2). The characteristics of the case study firms are shown in table 1. In terms of employment and sales, the 1998 sample consists of mainly small and medium-sized firms but also includes a couple of large firms. At the time of my interviews, the firms included were quite successful in terms their market performance. With a few exceptions, this is reflected in substantial export activities and annual growth rates in sales of at least 10%.

4 The 'Massachusetts miracle' and crisis: collective action and failure?

The industrial history of the Boston region has always been heavily influenced by close industry-government interactions and weapon production (Rosegrant and Lampe, 1992). After being settled by European immigrants in 1620, the New England region developed into the cultural, educational, trade and industrial center of the New World and was able to retain its importance in these functions until today. During the 19th century, manufacturing activities were heavily concentrated in the leather and textiles industries. Later, the machine tool industry also became important (Hekman, 1980a; Jong, 1987).

Already at the beginning of the 20th century, MIT (Massachusetts Institute of Technology) and Harvard University were considered to be among the top U.S. universities with excellent research facilities. In addition, the two universities encouraged close ties to industry. This had two major outcomes. First, both universities and their research laboratories were able to attract large amounts of federal funds for defense-electronics and computer research before, during and after World War II (Dorfman, 1983; Rosegrant and Lampe, 1992). Second, by the early 1920s, Boston had developed a tradition in entrepreneurial activities. There were already successful university spin-offs when Raytheon was started up by MIT engineers.

Table 1. Characteristics of case study firms in high technology industries of the Boston region, 1998 (sources: author's interviews, March 1998). Notes: '/' means 'information not available' or 'not applicable'.

Firm	Year established	Number of employees		Sales	Annual growth rate	Exports	Regional sales	Regional supplies
		World-wide	Regional	(US-$ million)	(% sales)	(% sales)	(% sales)	(% supplies)
				A. Computer and electronic equipment				
A	1988	20	20	9	/	5	80	10
B	1974	100	90	25	10	substantial	substantial	50-60
C	1984	1900	100	25-30	12	40	< 10	50
D	1961	275	275	25-27	10-13	10	10	100
E	1957	55000	/	/	/	/	little	little
				B. Instruments and related products				
F	1980	300	300	40-80	30	40	15	/
G	1961	1000	500	/	/	67	< 1	75
H	1967	65	65	10	20	28	25	60-70
I	1971	970	600	85	6	0	5-10	70
				C. Software and hardware services				
J	1987	70	35	10	12	1	15	50
K	1989	50	50	< 20	100	10-20	< 1	/
L	1973	430	150	45	15	60	< 5	> 67

Under the leadership of MIT's president Compton, university-industry relationships were further intensified after the war. The ARD (American Research and Development Corporation), the first venture capital firm in the U.S., was founded in 1946. It played an important financial role in the start-up phase of many high technology MIT spin-offs, such as DEC (Digital Equipment Corporation) and HVE (High Voltage Engineering). As a result of research activities during World War II and shortly thereafter, Wang Laboratories spun off from Harvard's Computation Laboratories in 1951. DEC followed in 1957, a spin-off from MIT's Lincoln Laboratories. Consequently, the Boston region became a major high technology innovation center in the U.S. (Dorfman, 1983; Saxenian, 1985; Malecki, 1986).

In the 1960s, the growth of high technology industries even accelerated. Intensified federal military and space research expenditures during the Korean crisis and the space race led to new technological opportunities (Rosegrant and Lampe, 1992). This resulted, directly or indirectly, in a total of about 175 MIT spin-offs during the 1950s and 1960s (Roberts, 1968; Keune and Nathusius, 1977). In addition, substantial private spin-off activities took place from companies like DEC and Raytheon (Malecki, 1986; Jong, 1987). A third group of high technology start-ups was unrelated to military expenditures or university research. These firms were launched by individual entrepreneurs close to their homes (Bathelt, 1990).

By 1969, more than 50% of the high technology firms surveyed operated a facility in Boston. Most firms were located along Route 128 which had been constructed as a major periphery ring highway, 10 miles outside of Boston, during the 1950s (Saxenian, 1985). High technology firms now benefited from the initial competitive advantage which induced further agglomeration tendencies (Krugman, 1991). Waltham became the core of the electronics and instrument industries. In Lexington, defense-related high technology firms located close to MIT's Lincoln Laboratories and Hanscom Field Airforce Base. Many high technology firms set up facilities in the industrial and research parks in the northwestern corner of Route 128, between Waltham and Burlington (figure 2). The whole development took place quite spontaneously (Keune and Nathusius, 1977).

Due to a number of structural problems (Harrison and Kluver, 1989), the Boston region experienced economic decline in the early 1970s. This was related to plant closures and relocation activities in the mature textiles and leather industries, a process which had already started in the first half of the 20th century, and substantial cutbacks in military expenditures after the Vietnam war. High technology growth, being particularly dependent on military expenditures at that time, slowed down as a result of the cutbacks. By 1975, the economic decline in the Route 128 area was so severe that Massachusetts registered the highest unemployment rate among all U.S. states (Ferguson and Ladd, 1986). In the late 1970s, however, Boston's high technology industries recovered and expanded at a fast pace. This revitalization was

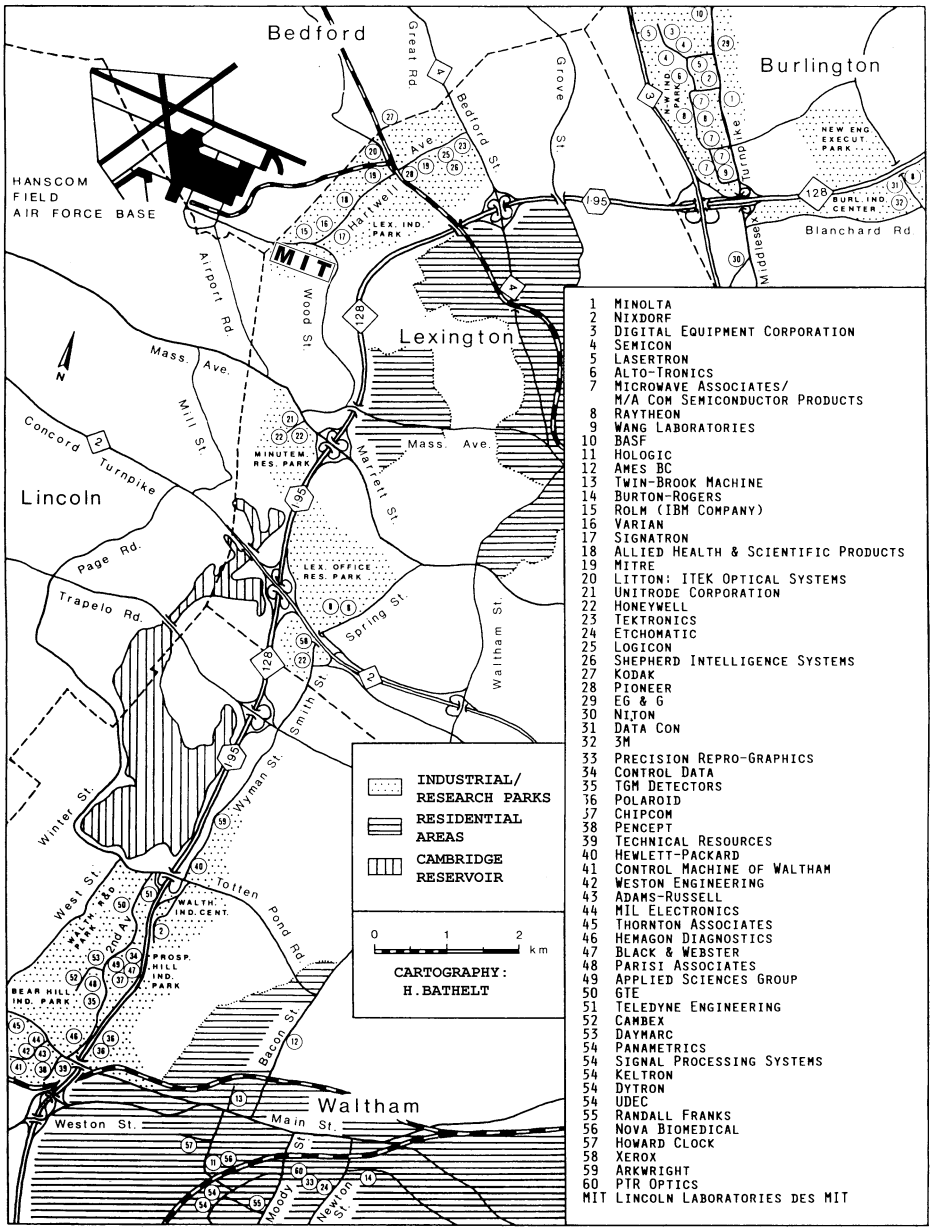


Figure 2. High technology firms along the northwestern parts of Route 128, 1988 (sources: Bathelt, 1990; 1991a).

related to increasing defense budgets under the new Reagan administration and the existence of a highly qualified and differentiated labor force to meet the requirements of growing firms (Dorfman, 1983; Sternberg, 1995). The most important force behind this upswing was, however, the expansion of the local minicomputer industry (Hekman, 1980a; 1980b; Saxenian, 1994). Minicomputer and related electronic equipment firms from the region were successful in entering new commercial markets and, thus, grew at a fast pace (MDES, 1985; Harrison and Kluver, 1989; Bathelt, 1990; 1991a).

To decrease dependence on the government, other high technology firms also reduced their military orientation by increasing private sector sales (Saxenian, 1994). During the 1980s, the growth of high technology firms continued, although the number of start-ups was in the decline. Most firms were still located along Route 128 but major expansions now took place closer to Interstate 495, a second periphery ring highway, 10-15 miles further away from Route 128 (Jong, 1987; Harrison and Kluver, 1989).

MIT and Harvard remained top U.S. universities, as measured by overall research performance (Malecki, 1986). In addition, many graduates of the more than 100 universities and colleges in and around Boston stayed in the region, even during the recession, and formed the basis of many industrial start-ups (see, for example, Bathelt, 1991a; Tödtling, 1994).[9] At the same time, a large number of multinational companies located new branch plants along Route 128.

Saxenian (1994, page 3) describes the industrial structure which had developed in the Boston region as follows: “The Route 128 region [...] is dominated by a small number of relatively integrated corporations. Its industrial system is based on independent firms that internalize a wide range of productive activities. Practices of secrecy and corporate loyalty govern relations between firms and their customers, suppliers, and competitors, reinforcing a regional culture that encourages stability and self-reliance. Corporate hierarchies ensure that authority remains centralized and information tends to flow vertically.” The significance of military production reinforced vertical integration tendencies and autarkic firm structures. The result was that important information about markets and technologies was not shared with other firms. Puritan traditions, strong hierarchies and formalized organizational structures supported these patterns.

[9] Bania et al. (1993) have provided evidence which suggests that this experience cannot readily be transferred to other regions of the U.S. They were unable to reveal statistically significant relationships between university research and local start-up activities within each high technology sector studied.

5 Regional decline and renewal in the 1990s

In the late 1980s and early 1990s, the Route 128 region underwent another period of economic decline and dramatic restructuring due to a crisis in its high technology economy (Saxenian, 1994; Sternberg, 1995; Kenney and von Burg, 1999). From 1987 to 1992, the number of employees in high technology manufacturing decreased from 136,900 to 114,200. In 1995, a mere 90,000 people were left in manufacturing (table 2). This means that 47,000 jobs, the equivalent of one third of the regional total, were cut within this 8-year period. When including service operations into the analysis, i.e. software, data processing and networking services, the job losses appear much less dramatic. Specifically, employment in the regional high technology economy experienced a moderate decrease from 169,100 in 1987 to 147,000 in 1995 and has remained almost constant in the second half of this time period (table 2).[10]

These figures indicate that compensatory effects between different sectors have taken place in industrial development in the Boston region. In the next sections of this paper, I will demonstrate that this is a consequence of different, unrelated processes in the various subsectors of the high technology economy. The analysis reveals that regional high technology industries are not tied to a single technological development path. The local firms are part of different value chains. In other words, they do not form a single network of overlapping supplier and customer relations. Some sectors, such as minicomputers and military electronics, have declined while others, such as software and biotechnology, have grown. This development was based on interaction and collective action between regional firms only to a certain extent (e.g. in electronic components).

a) Military electronics

Due to the dismantling of the communist regimes in Eastern Europe in the late 1980s, which marked the end to the Cold War, U.S. government military expenditures were cut and projects about new weapon systems (i.e. star wars) terminated or reduced to a minimum. This has hit the Boston region hard as it has traditionally received a large part of the federal defense budgets (Ferguson and Ladd, 1986; Sternberg, 1995). As a consequence of this, large producers of guided missiles, weapon systems, aircraft, communications equipment and military electronics have had to close or substantially reduce some of their operations. From

[10] It should be noted that the U.S. experienced a general economic upswing during this period. This does not appear to be a sufficient explanation, however, for the recovery of Boston's industrial structure.

Table 2. Number of high technology employees and establishments in the Boston region, 1987 - 1995 (sources: U.S. Department of Commerce, 1989; 1994; 1997). Notes: (1) The Boston region, as defined here, includes the counties Essex, Middlesex, Norfolk and Suffolk. (2) In some SIC groups, the number of employees was not exactly specified and had to be estimated.

		Number of employees			Number of establishments		
SIC code	Industry group	1987	1992	1995	1987	1992	1995
283	Drugs	1599	3429	3689	38	39	41
357	Computer and office equipment	25124	12951	6311	129	121	89
365	Household audio and video equipment	2385	1514	487	17	20	13
366	Communications equipment	34224	14720	12030	104	55	61
367	Electronic components and accessories	26956	21828	23902	308	281	310
372	Aircraft and parts	9260	7061	698	19	17	8
376	Guided missiles and space vehicles and parts	70	3810	0	2	4	0
38	Instruments and related products	37301	48928	42857	381	437	419
737	Computer and data processing services	32159	38406	57032	1108	1615	2397
Total	High technology industries	169078	152647	147006	2106	2589	3338
	- Manufacturing activities only -	136919	114241	89974	998	974	941

1992 to 1995, the number of people employed in the production of aircraft (SIC 372) and guided missiles and space vehicles (SIC 376) decreased from 11,900 to a mere 700. Further, employment in the communications equipment sector (SIC 366) shrank by two thirds between 1987 and 1995, from 34,200 to 12,000 (table 2).[11]

Many defense-related producers were prepared for this development. They had, due to their experience in the Vietnam era, already reduced their dependence on military expenditures in the 1970s and 1980s (Harrison and Kluver, 1989). It was estimated that about 50% of the high technology establishments in the region depended on military contracts for at least one third of their sales in the 1960s (Malecki, 1986). In another study (Bathelt, 1990), I estimated that this decreased to 20% by the late 1980s. Defense contractors have dramatically reduced their labor force within the Route 128 area or have closed down their Boston facilities, such as those for the production of guided missiles and space vehicles (table 2). The change in the customer base from military to private markets has often been associated with a decrease in employment.

This tendency is strongly exemplified by one interviewed producer of aerospace instruments which had initially focused on defense-related contracts. In the late 1980s and early 1990s, the firm had to downsize its activities due to a drastic downturn in military sales. The firm laid off about 1,000 employees between 1988 and 1998. Only 600 employees were left in 1998 when the market situation had stabilized again. Close, long-term contacts with near-by suppliers were an important factor behind successful adjustment and modernization of the production program, despite the fact that such linkages were often proprietary in character. As the product assurance manager stated with respect to suppliers, “[...] we try to focus in on local ones. [...] Our primary focus, believe it or not, is not even cost. It’s quality and delivery.” Between 1988 and 1998, the firm made a conscious effort to reduce the number of suppliers from 700 to just over 400 and increased its share of regional supplies from 55% to 70%. There is a lack of near-by customers, however, for which a good local supplier base cannot compensate.

[11] The communications industry also includes divisions of large defense contractors such as Raytheon, GTE Government System and General Electric (George D. Hall Company, 1988; Manufacturers’ News, Inc., 1997). The drastic decline of this industry is, thus, partially due to the reduction of federal defense expenditures. Another reason behind this decline is the deconstruction of the region’s minicomputer industry, a topic which will be dealt with in the next section of this paper. In addition, there were significant job losses in those segments of the communications equipment sector which were not closely related to the military industrial complex and the minicomputer industry (e.g. AT&T Network Systems). Overall, development in the region’s communications industry are still somewhat unclear and require further investigation.

b) Minicomputer industry

Since the late 1980s, the local minicomputer computer industry which had been so successful in the 1970s (Hekman, 1980a; 1980b; Saxenian, 1994) experienced a dramatic downswing. The number of establishments in the computer and office equipment industry (SIC 357) decreased from 129 in 1987 to 89 in 1995. The decline in employment was even more dramatic. In the same period, the number of employees in this industry group decreased from 25,100 to 6,300 people (table 2). As of today, the former minicomputer industry is virtually non-existent. This has also affected a number of related industries, such as communications equipment and electronic components and accessories, which had formed a part of the supplier and customer base for the computer industry.

Beginning with Intel's 286 and 386 processors, new inexpensive, technologically advanced PC generations, which were designed and produced in Silicon Valley, began to flood the former minicomputer markets and were able to replace them (Judge, 1997). In addition, PCs were designed as open systems, whereas the minicomputer industry had focused on proprietary (i.e. producer-specific) computer systems (Tödtling, 1994). The large minicomputer producers had underestimated the competition from the PC product segment. Saxenian (1994, page 100) describes the changing nature of competition as follows: "Initially, most Route 128 minicomputer firms did not recognize microprocessor-based technologies as a threat. They dismissed microprocessors as either irrelevant or silly, much as IBM had dismissed the threat of minicomputers two decades before. [...] The minicomputer makers also refused to abandon their proprietary architectures and operating systems, in spite of growing evidence that customers preferred the flexibility of open systems."

As a consequence, the minicomputer firms in the region had to drastically restructure their operations, reduce their labor force and close production facilities.[12] Wang Laboratories, one of the former key players in the regional growth path, went out of business and left its huge, impressive Lowell facilities behind. The firm did re-establish itself, however, in a related business segment as a provider of networking and desktop services, in a near-by industrial park. In an attempt to internationalize its

[12] Kenney and von Burg (1999) emphasize that Silicon Valley-based microcomputer firms also got into trouble when IBM's PCs gained market leadership. According to their analysis, this did not affect the region as much as in the case of Boston because the leading semiconductor industry of Silicon Valley offered a larger window of potentialities for further developments. In addition, Silicon Valley had a larger pool of supporting institutions for new ventures and start-ups than Boston (Kenney and von Burg's economy 2 institutions, such as venture capital firms). Saxenian (1999) doubts that this would be a sufficient explanation and, instead, argues that the superior growth performance of Silicon Valley over Boston is due to substantial differences in the manufacturing culture and organizational patterns between both regions. This is why technological breakthroughs did not occur in the Route 128 area (e.g. in the case of workstations) even though some of the original innovations were made here.

activities, the firm acquired Olivetti's computer services branch in 1988 and changed its name to Wang Global (*Frankfurter Rundschau* 1998b).

DEC, which was another incubator of high technology growth in the Boston region since the 1950s (Dorfman, 1983; Jong, 1987), terminated most of its manufacturing activities within the region (e.g. the former production of keyboards in Boston, storage devices in Springfield, power supplies in Burlington). Only the headquarter functions and research and development facilities, as well as marketing and maintenance, remain in the region. With the decline of the minicomputer industry, DEC has also given up its emphasis on proprietary systems and a vertically-integrated production structure. Electronic components and parts and peripheral equipment are now being acquired from external suppliers, largely from outside the New England region. Due to a loss of traditional market segments, DEC has extended its production program from hardware production to software and services. There is, however, still some business in the maintenance of old DEC systems that are still in operation.

Traditionally, supplier and customer linkages in Boston's minicomputer industry have been shaped by the firms' focus on self-reliance and secrecy (Saxenian, 1994). Supplier industries benefited from the high growth rates of the minicomputer industry, but information exchange often concentrated on low-level technologies. Spill-over effects did, thus, not spur the development of leading-edge technologies in the supplier sector. Due to the fact that manufacturing stages have been sold and outsourced to other firms, new supplier relations have developed in recent years. DEC has established a hierarchical business link program through which suppliers can lock into the firm's computer network. The closer the business relation, the more services and privileges are added to the business link account of a particular supplier. In some cases, proximity is an important factor despite the existence of internet relations (e.g. to establish just-in-time delivery). This has, however, not had much of an impact in Eastern Massachusetts because most of DEC's local manufacturing operations have been dissolved over the past decade. Overall, the reduction in manufacturing activities has had a tremendous impact on small specialized suppliers.[13]

In response to the question as to why the firm has remained in the Boston region, a manager from the corporate strategy and technology group replied that DEC "[...] still is a solid technology company. And you got more universities and technology

[13] One firm that provides customized high resolution monitors had originally located across the street from one of DEC's production facilities and had close linkages. After DEC terminated this supplier relation, the firm looked for other high-end customers within the region and was able to compensate this loss in sales within a short time period. This was possible because the firm was able to change their product design. In 1998, 80% of total sales still originated from within Eastern Massachusetts.

resources here than you got in a 50-mile radius elsewhere in the United States." Like most local firms that were interviewed, DEC actively recruits people from local universities (e.g. through co-op programs). Overall, the advantages of labor market pooling seem to be decisive in helping the region to sustain its competitive advantage and attract further growth.

In an attempt to establish a diversified computer firm with a strong market position comparable to that of IBM, Compaq, a Houston-based computer firm, acquired DEC in 1998 (*Frankfurter Rundschau* 1998a; 1998c; Siegele, 1998).[14] Drastic cuts in the overall workforce were a consequence of restructuring activities and technological synergies (*Frankfurter Rundschau* 1999b). In addition, the firm ran into unexpected problems. Compaq had difficulties to maintain its market shares against new low-cost competitors from within the U.S. These were especially successful in selling computers to internet users (*Frankfurter Rundschau* 1999a; Zepelin, 1999).

c) Computer software

To understand the importance of the high technology sector in Boston in the 1990s one must look at the rise of the computer software industry (Harrison and Kluver, 1989; Judge, 1997). Between 1987 and 1995, the number of establishments in computer and data processing services (SIC 737) increased from 1,100 to 2,400 and the number of employees from 32,200 to 57,000 (table 2). The growth of the software sector was originally driven by independent software applications of providers, such as Lotus from Cambridge. Recent growth in this sector though has primarily been based on the provision of internet services and applications. Lotus was an important trigger for the development of the regional software sector. Another significant factor was the trend to replace hardware through software adjustments. Increasingly, product changes and customization are done through software modifications based on meta- hardware components as opposed to actual changes in the hardware.

The universities of the region also provided an important source of highly-qualified software engineers. They are seen as a source of new ideas, qualified graduates and start-ups of new firms. One sales manger emphasized that "[...] Boston is one of the hotbeds in this area for software engineers." The high competitiveness of the local software industry is often not based on interactions with near-by customers, suppliers, competitors and universities. This is exemplified by one medium-sized software firm which has developed competence in a highly specialized market niche. Like other software producers, this firm follows an open-systems approach but, at the

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Employment had grown from 5 to 20 people from 1988 to 1998.

[14] Further acquisitions of important Boston-based high technology firms through competitors from outside the region were those of Apollo Computer by Hewlett-Packard and Lotus by IBM.

same time, is very careful in disclosing information to other firms about its own products. The owner of the firm pointed out that subcontracting in the industry is usually done locally.

A number of important hardware producers, such as DEC and Wang Laboratories, have totally restructured their production programs and extended their activities partially or fully into software production and computer services. These firms have tried to learn from the failure of the minicomputer industry and have entered new markets with substantial growth prospects. In my survey, I found another example of such a shift in production. One CEO classified his firm as being a software producer and integrator in the area of pre-press systems (i.e. editorial, advertising and pagination systems). Originally, the firm was primarily involved in manufacturing in this business. The firm provided the required hardware, the operating system, data base and other applications as turnkey solutions to its customers worldwide. The hardware concept was a proprietary one based on DEC's PDP-11 technology. Keyboards, cables and many other parts were produced in-house in the Route 128 area.

With the development of the PC as a standard platform, however, the structure based on proprietary systems and vertically-integrated production collapsed. This has caused major restructuring from hardware to software production based on open systems. According to the Sales Director of the firm, "[...] this makes it more complex because we have to manage pieces over which we have no control. [...] So, we still have the role of the integrator." As the firm has been forced to recognize, customers are no longer dependent on any one particular technology and can shift from one service provider to another.[15] Overall, the firm's labor force within the Boston region shrank from 1,000 in 1988 to 150 in 1998. Due to the shift in production, most of the former supplier relations, of which two thirds had concentrated in Eastern Massachusetts, were terminated.

Such shifts from computer hardware to software were typically the result of firm-specific (i.e. individualistic) learning processes rather than the effect of collective action. Nonetheless, such adjustment processes should not be viewed in isolation from the socio-cultural and institutional context within the Boston region. Most managers interviewed emphasized the importance of the local universities in designing sophisticated software engineering programs and the tendency of many

[15] This restructuring process was associated with a lot of conflict within the firm. Some employees left the firm and formed a spin-off company based on open systems in 1987 in the same business area because they were not pleased with how decisions were made during this period. They also recognized that especially smaller customers did not receive appropriate service. In establishing a new firm, these employees gained a number of customers from their former employer. The services provided by the new spin-off are also less standardized than those of the incubator and are better suited for small and medium-sized customers.

graduates to settle down within the region because of its attractiveness (see, also, Dorfman, 1983; Bathelt, 1991a).

d) Electronic components

Many producers of electronic components in the Boston region were originally quite dependent on the minicomputer industry. They served as an important supplier base for the local minicomputer producers (Bathelt, 1991b; Tödtling, 1994). When the minicomputer industry started to decline, the local customer base for these firms began to vanish. Employment in the electronic components and accessory industry (SIC 367) decreased from 27,000 in 1987 to 21,800 in 1992 (table 2). Since then, firms in this industry have been quite successful in acquiring new customer groups and restructuring their production programs and processes. As a result, employment has increased, reaching a level of 23,900 people in 1995. All electronic component firms surveyed exhibited this trend. After a period of decline, sales and employment have stabilized in recent years.

One engineering firm from the survey was able to successfully capitalize upon the growing market for customized electronic components. In recognition of this emerging market, the firm adjusted its products in a timely manner to meet the needs of customers outside the minicomputer industry. Due to the strategy of large customers to concentrate their respective activities in strategic business areas, the firm was successful with flexible, small-scale production runs and short-notice, troubleshooting services. The firm has always been quite dependent on a limited number of local customers. This has not changed despite the decline of the minicomputer industry. The firm's success in acquiring new customer groups has been due to the flexibility of its labor force and in-house adjustments in the production program, rather than being the result of collective action with suppliers and customers.

There is, however, some evidence which suggests that the recent upswing in the electronic components sector has not purely resulted from individual restructuring activities but has been related to interactive learning processes between firms located within the region. One good example of close, long-term producer-supplier interaction is provided by a medium-sized producer of high-quality printed circuits.[16] The vice president of operations expressed the need to establish trust relations with suppliers to be able to cope successfully with the dynamics of technological change. The suppliers are expected to provide the firm with key technologies, R&D support and problem-solving services. In recent years, the firm has increasingly recognized

[16] It should be noted that similar tendencies have been reported in interviews with several other firms.

that technological progress cannot be achieved in isolation. Innovation requires collective action because the engineering involved is very diversified and complex. It follows that the spatial proximity of core suppliers becomes an important issue (see, for instance, Bathelt, 1999). In terms of proximity, the interviewee mentioned that “[...] people sometimes underestimate the amount of service and support that it takes to do business with people. And having a good product is not good enough. You have to have good service [...] to make sure that the product is used the way it should be used. If a supplier is in difficulty, is troubleshooting a problem, [...] you have your people there to support the research and development and the troubleshooting that take place. So, problem-solving requires heavy support. And you can’t support only by phone. Most of the time, it has to be face-to-face. We have to get in [the supplier’s or customer’s facilities] and see what’s going on.”

Consequently, the firm acquires all their supplies from within the Boston region. In line with the arguments of Storper (1997) and Maskell and Malmberg (1998), some of the supplier relations are based on integrity and specific conventions rather than a formal contract. In terms of the danger of unintended knowledge transfers, the interviewee emphasized “[...] that there’s a lot of integrity in this business [within the region]. There is a lot of business that’s done on hand-shake. And I think if you had gained the reputation of doing that [of spreading sensitive information to other firms] nobody’s going to do business with you. So suppliers, application engineers do not [...] talk about what other companies are doing. They maybe talk to us what the industry trends are.” The electronic firms included in the survey all seemed to acknowledge the benefits of spatial proximity in terms of communication and adjustment processes with suppliers and customers. The manufacturing director of one firm pointed out that face-to-face contacts with suppliers help establish personal relationships and increase reliability.

The electronic component producers are more and more dependent on customers from outside the region. As a result, these customers become the driving force behind technological changes in production. Small and medium-sized electronics firms in the region have increasingly specialized on the fabrication of customized products. The lack of proximity to customers can be a problem in the early design phases of a new contract. As one manager mentioned, “[...] you need interaction with people because there has to be an understanding of what we do and how we do it.” The operations director of one user firm also supports this with his statement: “[...] we would like to have a local supplier [of electronic components] The big advantage is the flexibility of being able to get it that day if you need it but also on technical issues. It’s a hell of a lot easier to hop in my car [...] and go over [to that firm] and go through an issue. It’s a huge advantage really.” Intensive communication in the development stage seems to have a positive effect on performance. Another producer experienced

difficulties in finding local suppliers of electronic components because many firms have either relocated to other regions in the U.S. or have gone out of business.[17]

e) Instruments

The instrumentation industry in the Route 128 area has always benefited from the growth of the local minicomputer industry and its effects on the development of a highly skilled labor market and large pool of specialized suppliers of electronic components. Instrument firms have, at the same time, operated relatively independently from the minicomputer industry and have not had strong linkages with local computer firms. The strong decline of the region's minicomputer industry has, therefore, only had a modest impact on the production of instruments and related products (SIC 38). Employment in this sector increased from 37,300 to 42,900 between 1987 and 1995 (table 2). Most of the firms in this industry are small and medium-sized.

The technological development paths of the instrumentation and minicomputer industry have traditionally not been closely related to one another. Instrument producers have never developed important material linkages with minicomputer firms through input-output relations. As opposed to the supply side, instrument producers do not usually have customer relations within the Boston region because the area does not have a significant agglomeration of user industries. Customer connections which are essential to understanding the customers' technological needs are often established through a national and international network of engineers which operate as sales representatives and technical consultants. One instrument firm located in the Route 128 region, for instance, pointed out that they have always had to acquire their customers from far away.

In the case of one producer of process control instruments, sales within the Boston region accounted for only 1% of total sales in 1998. The firm was not affected by the decline of the minicomputer industry. Restructuring activities were, however, necessary because the firm had to shift its production from analog to digital technologies. Once this was done, it grew steadily throughout the 1990s based on incremental improvements in its products and processes. From 1988 to 1998, the number of employees in the Boston region grew from 250 to 500. The firm's ability to react flexibly to changing markets is, in part, based on its local supply base. The firm

[17] The manager pointed out that the suppliers "[...] all went down South or they all went overseas to be more competitive. And now there's a huge influx of all that coming back because the local supplier issue is so important." One supplier of electronic components was, for instance, acquired by a large multinational producer from outside the region. In order to cut costs, a large part of production was relocated to other company sites. Production is now divided between several locations in the U.S., India and China.

has increasingly subcontracted part of its production to key suppliers located in the region.[18] Overall, 75% of total supplies are acquired locally. Only a small proportion of the supply materials is, however, actually produced within the region.

Another interviewed instrument firm which produces specialized measuring equipment is also deeply embedded within the region's supplier base. According to the manufacturing director, the firm prefers to work with suppliers that will stay with the company over a long-term because "[...] after a while, you start understanding each others needs and how you can best support those. So if you reduce the supplier base the communication improves. If you keep changing the supplier base the communication is gonna go down. At this day and age, you can't afford poor communication." The firm consciously tries to acquire suppliers which are near-by. Over the past decade, efforts have been made to strengthen the local supplier base and, at the same time, reduce the overall number of suppliers. In 1998, 60-70% of the firm's total supplies originated from within the Route 128 region. As the manufacturing director stated, there are good reasons for this as "[..] a couple of our key suppliers are just down the street [...]. It's a lot better, from where we stand, to have suppliers near at hand because when you have these little glitches you can drive down the street in 5 minutes and get to a key supplier. [...] You can sit down and talk about the problems. When your supplier is in California or in the Far East you have problems. Communication is a lot harder. So we would really prefer to have suppliers as close as possible." It appears that such behavior has enabled local firms to develop a culture of frequent meetings based on in-depth, non-standardized communication.[19]

f) Biotechnology industry

The biotechnology industry is a relatively new high technology sector which emerged in the Route 128 region during 1980s (Bathelt, 1991a). This sector is based on genetic engineering technologies and is dominated by firms from the pharmaceutical, medical and agricultural industry. The growth process of the biotechnology sector cannot be easily described through the use of conventional industrial classification systems. This is because such classification systems do not integrate biotechnological activities into a separate category. The dynamics of this sector is,

[18] According to my survey, subcontracting within the region seems to be common because it requires effective communication, coordination and control.

[19] The manager of one firm mentioned that "[...] our number one supplier of electronic components, I mean, they stop by several times a week - and they are 25 miles from here - comes in and checks with manufacturing, sees if we need anything - then goes to engineering and asks what type of designs they are looking for or parts. Then they tell you what's coming up and what's disappearing. There is continuous communication."

however, reflected in the development of the local pharmaceutical industry. Between 1987 and 1995, the number of employees in this industry (SIC 283) increased by 130% from 1,600 to 3,700 (table 2). Further evidence for the importance of biotechnology research and production has been provided in Tödtling's (1994) study of industrial networks in the Boston region. He reported that, in 1992, about 10% of all U.S. biotechnology firms were located in Massachusetts. According to this analysis, the Massachusetts biotechnology industry accounted for 130 firms with a labor force of about 13,000 people.

The local biotechnology sector largely consists of small and medium-sized, research-intensive firms. The sector is dominated by young start-up firms, such as Biogen and Genetics, which were founded in the late 1970s and early 1980s and which have developed strong research links with regional institutions. First-class universities, such as Harvard and MIT, medical facilities and hospitals (i.e. the Massachusetts General Hospital) have specialized in different fields of biotechnology and biomedical research (see, for instance, Boston Redevelopment Authority, 1987). Rosegrant and Lampe (1992) emphasized that many firms of the local biotechnology sector emerged from the research carried out in these research institutions and have maintained strong linkages with them. In addition, local biotechnology firms rely on high-quality graduates from special programs of the local universities and colleges.

In terms of supplier and customer linkages, the local context is, however, not very important. Due to the absence of value chain-based linkages, the biotechnology industry does not have a great influence on the overall economy of the Boston region. Further, the significance of local research linkages is overshadowed by national and international cooperation with large firms interested in biotechnology research. Multinational pharmaceutical companies from all over the world (e.g. BASF, Hoffmann-La Roche (Boehringer Mannheim), Merck, Novartis (Sandoz) and Schering) have established joint ventures and strategic alliances with firms from the local biotechnology sector and world-renowned hospitals in their respective areas of specialization (Tödtling, 1994). It is not very likely that the commercial products of such cooperative research ventures would result in additional local production activities. Due to the international character of such interfirm cooperation, it is more likely that the results would be transmitted to the respective plant locations of the partner firms. The effect on the local economy might be quite limited as a result. This might contradict the expectations of many observers of the local economy that the biotechnology sector will have a large impact on the growth performance of the regional economy in the future.[20]

[20] One firm executive insisted that "[...] these things tend to go in cycles. We were the undisputed leader in minicomputers, you know, we got the DECs here, we had Apollo, all that. And along came

6 Conclusions: multiple trajectories, individual restructuring and interactive learning

There is no doubt that high technology industries in the Boston region have undergone dramatic restructuring in the late 1980s and early 1990s. The regional economy lost more than 45,000 high technology manufacturing jobs between 1987 and 1995. Among other factors, this was due to the decline of the minicomputer industry and the reduction of military budgets. In addition, high technology firms from Boston have had problems in competing with low-cost producers from other regions of the U.S. and from overseas. Due to relatively high living expenses and labor costs, firms in the Boston region are not very likely to expand their local manufacturing activities in the future. The high technology base of the region might, therefore, be increasingly based on know-how intensive research, engineering and service activities in the future.

One could argue that the crisis of the late 1980s and early 1990s was also due to a lack of 'unlearning capabilities' (Maskell and Malmberg, 1998) with respect to giving up old structures and replacing them by new ones. The minicomputer industry was not willing to give up their focus on proprietary technologies and was, thus, subject to being locked into an inefficient technological trajectory. The ability to generate knowledge and innovations in the future may, thus, depend on the willingness and capability of local firms to avoid lock-in situations.

Empirical evidence from the mid 1990s suggests that the Boston region has been able to recover from this economic crisis. Knowledge regarding the processes behind this recovery is incomplete though and needs further investigation. From the research presented in this paper, however, several conclusions can be drawn:

(1) In its historical development, the Boston region has repeatedly been able to overcome economic recession. The recent upswing in the mid 1990s has been marked by a shift in the economic focus from declining to growing sectors; that is, from minicomputers and military electronics to computer software and data processing services.
(2) It is quite misleading to view the region's high technology base as a relatively homogeneous set of industries tied into a single technological trajectory. I argue in this paper that the Boston high technology economy consists of multiple sectors which have followed different growth paths. This multiple trajectory framework helps to understand how the Boston region has been able to overcome economic crises in the past. I thus agree with Kenney and von Burg (1999) that the

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the microcomputers. All these companies said, it'll never fly but it did. And that's where Silicon Valley really came back from. But if you look at Cambridge now. [...] the microbiology engineering is all in Cambridge. [...] We're the leader in that field that hasn't gotten huge yet. But Biogen and all of these

conceptualization of technological development paths is important in understanding economic changes that have occurred in the Route 128 area. I reject, however, deterministic interpretations which could result from the application of such concepts (see, also, Saxenian, 1999).

(3) According to the findings presented here, individualistic learning processes and local supplier chains have been important in overcoming the regional economic crisis. Reconsolidation processes of established firms (e.g. shifts in production from hardware to software in the minicomputer industry) have often been a product of firm-specific rather than collective endeavors to overcome the crisis. At the same time, however, other high technology producers have benefited from close communication and adjustments with local firms, especially local suppliers (table 1). I have provided tentative evidence that such relationships have been especially prominent in the electronic components sector and, to some extent, in the instrumentation industry. The recent renewal processes can, however, only partially be viewed as an outcome of interactive learning and collective action within the Boston region. The economic recovery has primarily been driven by the growth of computer software and data processing services, a growth which was not based on local supplier or customer relations.

(4) My research results also suggest that more general interactions between firms, especially across sectors, were not very important. In the minicomputer industry, the leading firms focused on vertical integration, secrecy and self-sufficiency and did not rely on particular cross-sectoral linkages (Saxenian, 1994). In the case of military electronics, production is still based on proprietary technologies. The manager of one producer pointed out that suppliers do not have permission to sell the same parts to other firms. This does not allow the suppliers to apply knowledge gained from one customer to the needs of others. Such practices, which are still quite important within the Boston region, tend to slow down technological progress.

(5) The existing labor pool and university relations have seemingly been the most important resources behind the economic revival of the Boston region. Those owners and managers of high technology firms interviewed believe that the Boston region is even comparable to Silicon Valley in terms of its highly skilled workforce and its first-class universities. At the same time, they are aware of cost disadvantages and a trend in manufacturing to relocate to other regions.[21] This

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companies are sitting right down there. [...] It's high tech - just a different type."

[21] The manager of one firm claimed: "We have the Route 128 belt. That's what we call our Silicon Valley. That's right up the street - not too far from here. And that's where a lot of the design and development activities are going on - a lot of integrated circuit type manufacturers, they are constantly developing new types of products. So, I would say from an industry perspective and so forth it's good. On the other hand, I think a lot of the companies in the Boston area are gonna have a really tough time because they can't compete with what's going on. [...] And what's happening is a lot of

corresponds with Krugman's (1991) statement that labor market pooling is one of the key factors in understanding the agglomeration of high technology industries with the Boston region. Many firms actively recruit people from the local universities and benefit from specific university programs with respect to internet services and software development. There is a lot of enthusiasm when firm executives and observers (e.g. Judge, 1997) talk about the quality of local universities and their impact on the labor market. In addition, many engineers and managers who work in high technology industries and live in this region remain there through the course of their careers. This is related to the attractiveness of socio-cultural amenities and a specific life-style which has deep Boston roots and traditions.

(6) The above analysis suggests that the role of conventions behind this recovery is still somewhat unclear and needs further exploration. Regional concentration and specialization processes in Boston are not merely related to the existence of tacit knowledge, which is embedded in conventions and relations (Storper, 1997; Maskell and Malmberg, 1998). Due to a manufacturing culture based on corporate loyalty, secrecy and autarkic firm structures which developed in the region, the production and reproduction of conventions and relations was often restricted to the workplace level and ,thus, did not spread to other actors. Such firm-specific conventions and relations have obviously not played a major role in strengthening the regional competitive basis. Instead of tacit knowledge, the application of the concepts of institutional thickness (Amin and Thrift, 1995) and semi-codified knowledge (Asheim, 1998) might be more appropriate in understanding the capability of Boston's high technology economy to overcome structural crises. The region is characterized by a large variety of supporting institutions (e.g. venture capital firms, research laboratories, producer services) and the agglomeration of codified knowledge which tends to concentrate geographically (e.g. skills acquired at local universities). Such semi-codified knowledge (e.g. that of graduates in engineering and business administration who decide to stay within the region) can be applied to different industries and technologies. This has been an important requirement in shifting resources from one technological trajectory to another. Dorfman (1983) had already pointed out the importance of agglomeration economies in her analysis. The local universities are seen as an especially decisive asset to the region, through which high technology industries are being reproduced. This gives the Route 128 region a competitive advantage over other areas. Along with the already existing cluster of software and biotechnology firms and successful start-ups in these fields, this provides a sound basis for future growth in new high technology segments.

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companies are moving their manufacturing facilities, as you probably know, to lower-cost-of-living areas [...] to other countries or at least other areas of the United States - preferably non-union shops."

An additional advantage of the Boston region which is worth mentioning results from its strategic location with respect to European markets. In comparison to West coast locations, Boston is not only closer to Europe in terms of distance and time but also in terms of the manufacturing culture as defined by Gertler (1997). One executive described the effect of the time lag as follows: “When you live on the West coast it becomes almost impossible to do business with Europe during the work day. Here, I still got 3 or 4 hours to work with Europe.”. Another interviewee emphasized the importance of manufacturing culture: “[...] and it’s closer to Europe than the West coast - maybe has advantages, maybe like Silicon Valley and this area, because it’s closer to Japan. So strategically, this region for this simple reason will be growing. [...] It’s tough to say who has which advantage, o.k. - but certain cultures have a tendency to do, I would say, a little more comfortably dealing with the Boston area than with the West coast. Because, first of all, it’s 3 hours further. And second, you know, the culture here is more European.” In this respect, some of the rules and conventions of the local business community, such as formalism, hierarchy and respect, which were identified by Saxenian (1994) as being problematic to innovative activities, may actually be quite advantageous when dealing with European customers.

The industry structure and technological competencies, which have evolved in the Route 128 area, provide an excellent institutional setting for firms in particular high technology sectors. Through its high reputation as a technology region, Boston attracts further growth in these industry segments and helps new firms and start-ups to establish global linkages with customers. One executive expressed this as follows: “Being a U.S. headquarters in the software industry gives a company a sense of credibility. If we were a software company from some other country or some other part of the United States - from South Dakota - there may be less credibility with our customers. Being a U.S. company from Boston - you know, a hotbed of technology - with global operations I think gives our customer [...] security.”

Overall, the Boston region has not been an area where network relations and interactive learning have been important in the past (Saxenian, 1994). Preliminary evidence suggests, however, that this might change in the future, especially as small and medium-sized firms recognize that close supplier-producer-user interaction can stimulate innovation processes. Thus far, the region does not correspond with Lundvall and Johnson’s (1994) conceptualization of an all-interconnected learning economy. There are different subsectors in the regional high technology economy which depend on different forces and unrelated processes. They are not tied into a single technological trajectory.

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