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Open systems and regional innovation: the resurgence of Route 128 in Massachusetts¹

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Introduction

The Boston area has the highest concentration of colleges and universities, research institutes and hospitals of any place in the world. The plethora of graduate research programmes suggested that the industrial future of Massachusetts was secure in the emerging knowledge economy of the late twentieth century.

However, the research intensity of the region has not insulated the state from the vicissitudes of the business cycle. For example, after enjoying a ninety-month expansion labelled the 'Massachusetts' Miracle', the Commonwealth lost one-third of its manufacturing jobs between 1985 and 1992. The country's first high-tech region had seemingly lost industrial leadership much more quickly in the new industries of the late twentieth century than in industries first established in Massachusetts in the nineteenth century.

The simultaneous collapse of the minicomputer and defence industry, with the end of the Cold War, touched off a downturn which, added to the long-term contraction of traditional industries, suggested that industry in Massachusetts was in terminal decline. Combined with the setbacks in these major markets was the emerging prominence of Silicon Valley, which was fostering and commercialising innovations much faster than was Route 128, and often in the same technologies. Clearly, few were willing to bet on the resurgence of Route 128.

Nevertheless, the predictions of industrial gloom turned out to be wrong, or at least premature. A return to growth beginning in 1992 long surpassed the 'Massachusetts' Miracle'.² Why the rise, the crash, and the rise again? Certainly the decline of the mini-computer industry and cutbacks in defence expenditures are part of the story, but not, in themselves, an explanation.

In this chapter I seek to explain the resurgence of Route 128. It was not widely predicted and the explanation is not obvious. In fact many were so convinced of the terminal decline of New England as a site of industrial production that articles continue to be written on the decline of the region years after its resurgence. Something about the region has given it the resilience to bounce back from 'structural' decline.

If the resurgence and the basis of the region's competitive advantage had to be accounted for in a two-word summary, my candidate would be 'technology management'. Industries have come and gone but, fortuitously, Massachusetts has sustained a regional technology management capability. But my candidate is not an obvious one. The notion of technology management is rarely invoked in discussions of competitive advantage and industrial growth. It seems to be lost within the white spaces of business organisation charts, and in the hallways of higher education it is to be located somewhere between the departments of engineering, management and economics.³

This chapter seeks to bring 'technology management' into the discussion of the reasons for regional growth and decline. My treatment of the notion bridges three institutional domains: business model, production system and skill formation. I use the idea of a 'productivity triad', shown in figure 9.1, to focus attention on the interrelationships among the three domains and the mediating link of technology management capability between the inputs and outputs of an enterprise or a region's production system. My hope is that the productivity triad will also sharpen our understanding of innovation dynamics in regional growth.

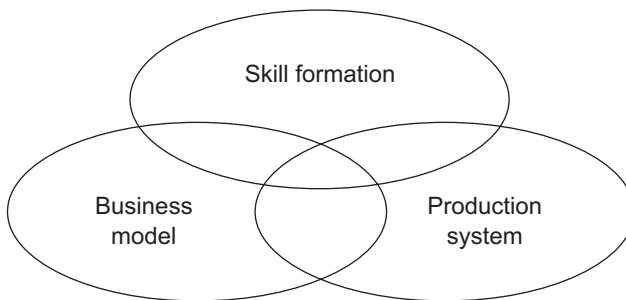


Figure 9.1 The productivity triad

I argue that the severe decline of 1985–92 in Massachusetts can be explained in terms of the emergence in Silicon Valley of a new model of technology management that undermined Route 128's competitive advantage in a range of industries. But, fortunately, the economic contraction did not destroy the region's production or skill formation capabilities. It put them under pressure, but the severity of the decline involved the 'creative destruction' of a business model that was no longer capable of driving regional growth. In its place a new business model emerged more suited to exploit the region's technological heritage and unique production capabilities. The decline played a critical role in the resurgence.

The business model was the weak link in Route 128's 'productivity triad'. The hierarchical, vertically integrated, organisational structure inherited from past successes had turned into a disadvantage. Its weakness was only exposed

with the emergence of a new model in Silicon Valley. In head-to-head competition with the new, the old business model disarmed the region's inherited technological and production capabilities and choked the region's growth potential. I argue that the return to regional competitiveness can be explained in terms of the emergence of a new 'focus and network' business model that fostered a range of 'cluster dynamics' and thereby established the institutional foundations for a regional 'open systems' model of innovation. Fortunately, the new business model revitalised the region's unique heritage of technological and production capabilities and skill base, and thereby replaced the forces of decline with new regional growth dynamics.

That something new has happened is beyond dispute. But without a deeper understanding of the processes involved it gives policy makers little guidance with regard to sustaining regional growth. The idea of the productivity triad suggests that advancing or sustaining regional growth depends upon the ability to keep all three elements of the productivity triad 'in sync' in a world of interregional competitiveness. These are the enabling conditions that support a region's technology management capability.

Furthermore, the productivity triad offers a framework for exploring the sources of a region's competitive advantage and of regional growth and decline. While the productivity triad points to relationships among the constituent elements, each can be examined in terms of links to the others. I start with the business model.

The open systems business model

The entrepreneurial firm⁴ was the driver of growth during both the Massachusetts' miracle and the resurgence periods. As a business model, the entrepreneurial firm is driven by a *technology-market dynamic*, a mutual adjustment process that advances a firm's technology capability as it refines its product concept in the market. Firms pursue emerging market opportunities by developing unique production capabilities, often of a technological form, but the process of developing such capabilities creates new product concept possibilities and thereby the opportunity to redefine the 'market'. A redesigned product that better meets customer needs sets the technology-market dynamic in motion again.

In the course of the Massachusetts' miracle a series of firms led by techno-entrepreneurs (often benefiting from government orders and research sponsorship) invested heavily in emerging computer-related technologies and established new markets. They joined others that were specialising in defence industry products and systems. The rapidly growing new firms organised according to the business model of vertical integration. This had a series of consequences.

Both the business model and the technology architecture of the leading enterprises were of the closed-system type.⁵ DEC's components, for example, were hardwired to one another. The microprocessor, the motherboard,

the memory chips, the disk drive, the operating system, the display screen, the software programmes, the printer, the printer microprocessor, the printer engine software, all of the computer peripherals were designed according to a proprietary (and closed) architecture.⁶ Sub-contractors made peripheral parts but were not encouraged to develop independent design capabilities. This is not surprising: it was the business model that had served the nation well for roughly a century (Chandler, 1977).

What was inconceivable was that these highly successful high-tech companies, leaders in the rapidly growing markets, could stumble on the technological side. They were first movers in rapidly growing markets and they were integrated with the innovative milieu centered on Boston's universities and research institutes. But they did stumble, collectively. Ironically, their weakness was technology management, individually and collectively.

The miracle years in Massachusetts (late 1970s to 1985) were also a time during which new business models, with superior new product development and innovation performance standards, were being developed in other regions. The Japanese extended the Toyota production system to the Canon model that set new standards for rapid new product development and incremental innovation (see table 9.1).⁷ This model established a technology management capability that integrated applied research and production in the service of product-led competition. The Canon model established new performance standards in time to market for new product development. A new technology-pull model of industrial innovation accompanied the new business model (Best, 2001). The Canon production system, however, did not pose the biggest threat to Route 128.

Route 128 companies rarely competed head-to-head with the Canon model. Industrial enterprises in Massachusetts had never developed high-volume manufacturing capabilities. Consequently, they were not vulnerable in industries like consumer electronics, automobiles, and electrical products in which the Japan enterprises were rapidly gaining market share. The vulnerability of Route 128 was to a third business model, one that emerged first in Silicon Valley. This 'open-systems' model established new performance standards for disruptive, as distinct from incremental, innovation. It was this vertically disintegrated but systems-integrated business model that exposed the weaknesses of Route 128's business enterprises and undermined the engines of growth in New England.

The 'open-systems' or focus and network business model is one in which firms specialise in unique capabilities, usually involving a technological dimension, and join networks to partner for complementary capabilities. Success at capability specialisation in high-tech usually involves the development of technology teams that span a range of scientific and technological disciplines.

The open-systems business model can be described in terms of the principle of systems integration, much as vertical integration historically fits the principle of *flow*.⁸ The new business model unleashed the internal technology-market dynamic from containment within vertically integrated enterprises to

Table 9.1 Production systems model

1 <i>Production systems</i>	2 <i>Exemplar breakthrough</i>	3 <i>Performance principle</i>	4 <i>Production capability</i>	5 <i>Application management</i>	6 <i>Production organisation advance vehicle</i>	7 <i>Technology</i>	8 <i>Industrial</i>
PS1	Armoury	Standardisation	Interchangeability	Product parts	Product engineering	Specialist machine	Open
PS2	Ford	Cost (economies of time)	Flow	Single product	Throughput efficiency (synchronisation)	Exogenous (R&D lab pipeline)	Vertical integration
PS3	Toyota	Flexibility and quality (inventory turnover)	Flow	Multiple products	Incremental innovation (cellular manufacture)	Process innovation (shopfloor incremental AR)	Closed
PS4	Canon	New product cycle-time	Flow	New products technology	New product development	Applied R&D (design and manufacture) DR+AR	Closed
PS5	Intel	New technology cycle-time	Systems integration	Technology innovation (multiple technologies)	New technology development	Technology integration teams (R&D and manufacture) BR+DR	Open

Notes: AR = applied research; DR = developmental research; BR = basic research.

drive a whole range of specialty component suppliers (not only those along the ‘value chain’ but across ‘value networks’). Sun workstations, for example, were designed with common interface rules and operating system source code to plug in microprocessors from Intel, IBM, AMD, or Motorola; display screens from Sony or NEC; disk drives from Seagate or Quantum; memory chips from Hitachi or Samsung; printers from HP or Epson. In leading companies like Intel, HP and Sun it combined a leadership–ideas dynamic with the technology–market dynamic.⁹

These internal dynamics, in turn, set in motion the processes identified in ‘cluster dynamic’ or regional growth dynamics model shown in figure 9.2.¹⁰ The new business model, enjoying increasingly far-flung applications, has proven highly competitive against both the Canon (closed system) and the Big Business (vertical integration) models. It is the organisational cornerstone of a new competitive advantage based on a regional model of innovation.¹¹ Three innovation dynamics can be distinguished.

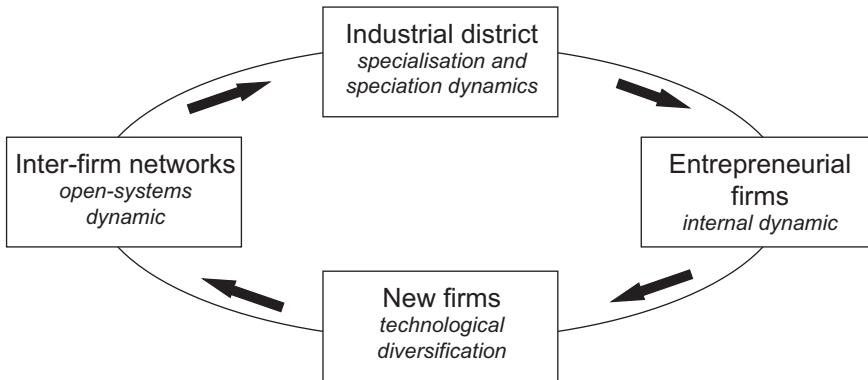


Figure 9.2 Cluster growth dynamics

Techno-diversification

The cluster dynamics of figure 9.2 is constituted by a virtuous circle of entrepreneurial firms driven by an internal technology–market dynamic generating both growth and new technological opportunities which, in turn, foster firm creation in emerging sub-sectors followed by new patterns of inter-firm networking. In the process regional innovations dynamics are fostered as the techno-diversity of the region increases and with it the probability of new technological combinations and the emergence of new entrepreneurial firms.

Examples of the repetition of the virtuous circle of regional dynamics leading to enterprises specialising in new technological ‘species’ in different technological domains are commonplace in the Massachusetts of the 1990s. One example is that of data storage systems, the ‘filing cabinets of the electronics age’.

EMC is an entrepreneurial firm that simultaneously has developed a unique capability and spawned a new industrial sub-sector. The company began as a supplier of add-on memory boards for the minicomputer market in 1979, moved into mainframe storage a decade later, and ‘added software to help manage its boxes as it made the switch to open systems in the middle of this decade’ (Degman, 1998, p. 1). EMC has achieved the leading edge in storage technology with an engineering staff which, in 1998, totalled 1,200 and an annual research budget of \$0.333 billion. In the same year the company opened a 682,000 square foot facility in central Massachusetts to test, qualify and assemble computer storage systems.

EMC has ‘spawned a new generation of software and service companies providing ways for corporations to monitor and manage data, back up and protect it, find and fix disk-storage bottlenecks, and warn desktop computer users to clean out their hard drives before they run out of space’ (Rosenberg, 1999). For example, a co-founder of EMC and a ten-year employee have formed StorageNetworks, a company that offers businesses data-storage

services on the networking model of telephone switches or electrical power generators. Other nearby companies that are driving and redefining the data-storage business, each with a unique specialty are Astrum Software (monitors disk-storage usage at each PC and server within a department), HighGround Systems (storage research management), Connected Corp. and Network Integrity, Inc. (backup systems) (Rosenberg, 1999).

The eleven firms that have spun out of Cascade Communications in the internet switching equipment sector are another example. All are located north of the Massachusetts Turnpike on I-495, a Boston ring-road outside but paralleling Route 128.¹² The emerging firms specialise in a range of products and services unified by the integration of hardware and software required to move data, voice and video over networks. While the region has historically been a centre for communication switching equipment (ex-AT&T's Lucent Technology's 2 million-square foot manufacturing site is in nearby North Andover), many of the new firms can be traced to the technological capability and skill base created at Cascade Communications. Cascade specialises in frame relay technology for 'efficiently directing the congested streams of data flowing across phone lines'. Sycamore, likewise, combines networking and optical technologies. Each of the companies, however, specialises in a distinctive technological capability and uses open-system architecture. Principals in nine of eleven of the startups had been employed at Cascade (Zizza, Pelczar and Eisenmann, 1999). Several principals had worked at the Advanced Network Group of MIT's Lincoln Laboratory, at Motorola/Codex, and at DEC.

The examples of data-storage equipment and telecommunications switching equipment are leading cases. But they represent a large class of business enterprise genealogies in which the emergence of regionally networked groups of firms can be traced to the technology and market dynamic of an entrepreneurial firm. Other examples in the Route 128 region include semiconductor equipment manufacturers (Eaton Semiconductor, Varion Ion Implant, Teradyne, Micrion); electronic test equipment suppliers; digital signal processing semiconductors (Analog Devices, Mercury Computer Systems, Alpha, BKC Semiconductor, C. P. Clare); electro-medical products (over twenty companies led by HP, now Agilent); biotechnology; genome industry (nearly 200 Massachusetts's companies in 1998); enviro-technology; pump laser equipment (MIT Lincoln Labs, Lasertron); infrared imaging systems ('Lab 16' Raytheon, Honeywell Radiation Center, Lockheed Martin Infrared Imaging Systems, Telic Precision Optics, Inframetrics, Inc.); and industrial automation (Foxboro Instruments, Groupe Schneider's Amicon Division).

CorpTech, a data-processing company, categorises America's small and medium-sized (under 1,000 employees) 'technology manufacturers' (most of which are privately held) in seventeen industries as shown in table 9.2. The dispersion is indicative of the diversity of industries associated with Route 128. The mix of high-technology manufacturing in Massachusetts, with approximately 2 per cent of the nation's population, is remarkably similar to that of the nation as a whole. CorpTech estimates that over 8 per cent of America's

Table 9.2 Techno-diversification of Massachusetts' (MA) manufacturers (January 1999)

<i>Companies</i>	<i>MA</i>	<i>%</i>	<i>US %</i>
Factory automation	337	10.5	12.1
Biotechnology	151	4.7	3.5
Chemicals	95	3.0	4.1
Computer hardware	35	13.6	13.8
Defence	56	1.7	2.1
Energy	105	3.3	4.5
Environmental equipment	203	6.3	7.1
High-tech manufacturing equipment	421	13.1	12.6
Advanced materials	159	5.0	6.6
Medical	248	7.7	6.3
Pharmaceuticals	95	3.0	2.5
Photonics	240	7.5	5.0
Computer software	993	30.9	24.8
Sub assemblies/comp	530	16.5	17.2
Test and measurement	378	11.8	11.2
Telecom and Internet	415	12.9	15.5
Transportation	92	2.9	3.6
US holding companies	245	7.6	8.4

Source: CorpTech Directory of High Tech Manufacturers. CorpTech tracks America's 45,000 plus technology manufacturers with under 1,000 employees (90 per cent are 'hidden' private companies and the operating units of larger corporations). Of 42,342 US entities, 3,242 or 7.7 per cent are located in Massachusetts. These are independent companies, subsidiaries of major US corporations, and American operating units of foreign companies. Data extracted with permission from CorpTech website: www.corptech.com

small and medium-sized high-tech companies are based in Massachusetts, with a total of over 200,000 employees.¹³

These data support the theme that a process of techno-diversification has driven the resurgence of the Massachusetts' economy. Technology management in the Massachusetts' miracle growth industries of minicomputers and defence was locked up in vertically integrated enterprises. The downturn was critical to the upturn, as the demise of these enterprises facilitated the transition to an open-system multi-enterprise model of industrial organisation. The accompanying decentralisation and diffusion of design combined with a heritage of technological skills and capabilities to fuel the internal growth dynamic of entrepreneurial firms, which, in turn, fostered techno-diversification and regional innovation dynamics.

Open-systems networking

The box at the left of figure 9.2 represents inter-firm networking. Three types of inter-firm relation can be distinguished: market, closed-system, or *keiretsu*, and open-systems networking. Inter-firm relations are structurally linked to intra-firm organisation: Big Business and arm's-length market-driven supplier

relations, the *kaisha* business model and *keiretsu* long-term supplier relations, and entrepreneurial firm and open-systems networking. The *kaisha* business model fostered the principle of multi-product flow and achieved performance standards (cheaper, better, faster) which established the 'new competition' of the 1970s and 1980s.

The third type is open-system networking, commonly referred to as 'horizontal integration', multi-enterprise integration, co-operation, networking or affiliated groups of specialist enterprises. Open-systems networking is the inter-firm counterpart to the increasing specialisation of the entrepreneurial firm. It has proven effective at both rapid new product development and innovation and, consequently, became the new competition of the 1990s. The open-systems model depends upon inter-firm networking capabilities.

Inter-firm networking has evolved with the shift from price-led to product-led competition. This entails integration of manufacturing and new product development processes. But rapid new product development is not simply adding a product (multi-divisional diversification): increasingly it involves a whole group of specialist companies operating at different links along the product chain or at different nodes in the value networks.

Open-system networks convert the inescapable dilemma of the individual entrepreneurial firm into a growth opportunity for a region's collective enterprises.¹⁴ Abandoned possibilities are simultaneously opportunities for new divisions within subsidiaries or spin-offs or for new firm creation. The pursuit of new capabilities also opens new inter-firm partnering possibilities for complementary capabilities. Ease of entry, as well, enhances the regional capability for firms, existing and new, to respond to new market and technological opportunities.¹⁵

Open-systems networking is a model of industrial organisation that fosters specialisation and innovation. Historically, open systems prevailed in the design-led industrial districts of the Third Italy. More recently, the emergence of systems integration capabilities in technology has both fostered open-system networks and developed because of them. In both cases the business model of specialisation and inter-firm networking form an internal-external dynamic that fosters innovation and growth.

The starting point remains the technology capability/market opportunity dynamic that drives the entrepreneurial firm, the source not only of the growth of the firm but of a derivative set of regional growth dynamics. But the internal dynamic of entrepreneurial firms simultaneously enhances *regional* growth potential. Whether or not the potential is realised depends, in part, upon strategic choices made within the entrepreneurial firm and the extent of inter-firm networking capabilities.

The firm's dilemma is either a cluster's constraint or opportunity. The firm's dilemma is a *cluster constraint* in a region populated by enterprises that are vertically integrated.¹⁶ But the firm's technology choice dilemma is a *cluster opportunity* in a region with 'open-system' networks.

The goal of the entrepreneurial firm is to develop the organisational capabilities to differentiate the firm's product in the market place and establish a

market niche and an ongoing relationship with customers. Success requires product redesign and development capability. To the extent that firms are successful, the mode of competition shifts from price-led to product-led. The rebounding pressures of product-led competition in the market on the internal organisation of the firm reinforce the drive to develop unique products and production capabilities. A new dynamic between internal organisation and inter-firm competition is established. Regions that make the transition to product-led competition can enjoy a competitive advantage over regions in which the dominant mode of competition is price. Product-led competition engenders the entrepreneurial firm. The entrepreneurial firm, in turn drives the new internal/external dynamic. Success in the marketplace increasingly depends upon product development, technology management and innovation capabilities.

Inter-firm networking offers greater flexibility for new product development and innovation than does vertical integration.¹⁷ Ironically, networking can foster the social relations necessary for effective co-location of specialist but complementary activities more easily than can vertical integration. While a vertically integrated company operates under a single hierarchy which can direct departments to co-locate, it does so within a bureaucracy and a set of technologies that were originally designed for different purposes. They become embedded in social systems and individual career paths within the firm that can offer resistance to organisational change. Open-systems-networking offers a range of co-design possibilities without locking an enterprise into any single design.

The Internet is a great facilitator of open systems networking. In fact, the Internet is an archetypal open-systems technology. It establishes interface rules that enable design modularisation. The Internet makes it possible to manage supplier relations by seamlessly integrating information across different computer systems, parts lists and even design programmes. All-but seamless integration across businesses enhances the simultaneous increase in specialisation and integration that Adam Smith identified as the principle of increasing specialisation.

As an easy plug-in system for specialist companies, the Internet lubricates the internal–external dynamics that spawn entrepreneurial firms. But it can also be seen as a metaphor for networking in general, and is thereby a target for policy makers seeking to increase entrepreneurial firms. In this, the Internet is the new invisible hand, but one that assists the creation of entrepreneurial firms and regional innovation.

The *new firm creation process* is itself an aspect of mutual adjustment. Just as the dynamics associated with new product development involve a continuous redefinition of product concept, carrying out the process can foster a proliferation of firm concepts. Diversity and the principle of variation, or increased speciation, mean the creation of new firm concepts. This process is enhanced in open-system networks in which specialist new firms can readily plug in to existing product chains. This process suggests that the strategies of firms are themselves shaped in the ongoing practice of refining a firm's

concept or specific characteristic by which it distinguishes itself from other firms and thereby derives its market power.

The entrepreneurial firm startup system is particularly strong in the Silicon Valley and Route 128/495 high-tech regions in the USA and in the design-led and the fashion industries of the 'Third Italy'. Taiwan, Ireland and Israel have all established variants, if on a smaller scale. The greatest attention has been focused on financial markets as the enablers of entrepreneurial firm emergence and development. Venture capital and 'initial public offering' capabilities are certainly contributors to the high rates of new firm creation in both Silicon Valley and Route 128/495. As important as financial commitment is, the driving force must be the technological and market opportunities for establishing a firm with the profitability to make an attractive return to suppliers of finance.

The resulting open-systems business model is a business system that expands opportunities for yet more entrepreneurial firms. Collectively the open-systems business model sets higher performance standards in rapid new product development and disruptive innovation (as distinct from continuous improvement or incremental innovation). It is a driver of growth. Wealth creation involving technological advance and techno-diversification is a process analogous to Adam Smith's principle of increasing specialisation as applied to technological capability.

Techno-diversification and networking enhance both new product development and industrial speciation, or the creation of new industrial sub-sectors. The protean character of technological capability, particularly evident in high-tech sectors, is a feature of industrial change even in the oldest sectors. The electronics industry morphs into, for example, an information and communications sector. Furniture becomes interior design and furnishing. The process of industrial speciation cannot be done within a single firm. In fact, the very success of a firm's pursuit of one technology's trajectory can create obstacles to technological transition; hence the role of networks by which new entrants can focus on a technological capability and partner for the complementary capabilities. Regions with open-system networks have low barriers to entry for new specialist firms. This process drives down the time for technological change and the process of new sub-sector formation.

Regional specialisation and innovation processes

The upper box in figure 9.2 signifies the extent of capability specialisation and technological diversity within a regional population of industrial enterprises. Specialisation has regional and inter-regional dimensions. Greater specialisation internally is a measure of the technological diversity within a region. Greater specialisation externally is a measure of uniqueness of the regional capability and thereby of regional competitive advantage.

Greater diversity is particularly relevant to innovation. An industrial district, unlike any single firm, offers the potential for new and unplanned technology combinations that tap a variety and range of research- and production-related

activities. Open systems offer wider opportunities to foster creativity, fill gaps, replenish the knowledge pool and match needs to research.¹⁸

Regional innovation capabilities lie behind the competitive advantage of 'low-tech' high-income industrial districts common to the 'third Italy'. Such districts have developed a competitive advantage in design capabilities that have fostered industrial leadership in a range of design-led or 'fashion industries'.

Recently, high-tech regions have developed similar capabilities for rapid design change and industrial innovation. In fact, regions such as Silicon Valley and Route 128 have developed regional innovation capabilities embedded in virtual laboratories in the form of broad and deep networks of operational, technological and scientific researchers which cut across companies and universities. Silicon Valley project teams are continual combining and re-combining across a population of 6,000 high-tech firms, making it an unparalleled information and communication technology industrial district.¹⁹

The core of the innovation process in this model is the fillip given to new product development (NPD) by the differentiation and integration process (see figure 9.1). Firms under strong competitive pressure and in demanding markets are seeking to push ahead with product improvements and new products as fast as possible. In doing so they encounter technical problems that they do not know how to solve, and they search for solutions, dipping into the specialist technological and scientific bodies of knowledge that are available in other firms, in universities and elsewhere. The companies best at effective and fast NPD have developed the capability to integrate technologies, starting with software and hardware. They know where particular kinds of knowledge and expertise can be located and how to dip into the pool of technological and scientific knowledge and expertise to solve particular problems. It is likely that this knowledge will be in identifiable 'chunks' related to the needs of the particular firms and industries and to the characteristics of the science and technology.

Models of innovation are associated with different business models. The *kaisha* variant of the entrepreneurial firm decentralises design and continual change into the operating units. The rapid gain in Japanese market share in many industries in the 1970s and 1980s was achieved, in part, by designing a complementary incremental innovation capability into production. It fostered a technology-pull model of innovation.

The regional model of innovation derives from the open-system regional growth dynamics (the diffusion and development of a range of growth dynamics issuing from the entrepreneurial firm). An American variant is the leadership and design dynamic which combines top-down and bottom-up actions captured by Andrew Grove's leadership-design dynamic. Techno-diversification, technology integration, new technology combinations and industry speciation are all elements in processes that advance the technology capabilities of a region.

The regional growth dynamics model fosters combined development and diffusion of innovation. Regional innovation refers to processes that not only

trigger the regional growth dynamics but which reshape it via the process of industrial specialisation. Thus the regional growth dynamics from an infrastructure for new industry incubation and formation.

The idea of regional innovation dynamics suggests a *collective entrepreneurial capability* as a basis for regional competitive advantage which, like its enterprise-level counterpart, can be conceptualised as a technology market dynamic, but at the regional level.²⁰ Industrial districts compete against one another. Given different paces of technological development or a shift by one region to a higher model of technology management or a new technology platform, the losing region risks losing a whole swathe of enterprises.

As the networking capabilities of a region become more robust, the more that region takes on the semblance of a virtual collective entrepreneur. The virtual collective entrepreneurial firm is a self-organising change agent composed of networked groups of mutually adjusting enterprises.²¹ The collective entrepreneurial firm is a composite of networking firms that collectively administers the regional growth dynamic processes of figure 9.2.

High-tech industrial districts such as the one found in Massachusetts:²²

- Drive the new firm creation process. Intel's R&D strategy is based on 'the acknowledged role of the spin-off or startup', not in creating but in exploiting new ideas.
- Create a collective experimental laboratory. Networked groups of firms are, in effect, engaged in continual experimentation as the networks form, disband and reform. Both the ease of entry of new firms and the infrastructure for networking facilitate the formation of technology integration teams in real time.
- Expand the number of simultaneous experiments that are conducted. A vertically integrated company may carry out several experiments at each stage in the production chain, but a district can well exploit dozens simultaneously.
- Foster design modularisation and, with it, the decentralisation and diffusion of design capabilities. In computers, IBM got the process underway with the modularisation of the 360 computer which created an open system. This was greatly enhanced when the design modules for the operating system and the microprocessor were developed by Microsoft and Intel.²³ The resulting standards have created enormous market opportunities for specific applications software.
- Counter the inherent uncertainty of technological change with the potential for new technological combinations. This feature of the regional networking model of innovation is captured by a recent review of retrospective surveys of the conditions critical to successful innovation.

A survey by Ronald Kostoff (1994) finds that the first and most important factor is a *broad pool of advanced knowledge*. Kostoff's review indicates that 'an advanced pool of knowledge must be developed in many fields before

synthesis leading to innovation can occur'. This advanced pool of knowledge, not the entrepreneur is the critical factor. In the words of Kostoff (1994, p. 61):

The entrepreneur can be viewed as an individual or group with the ability to assimilate this diverse information and exploit it for further development. However, once this pool of knowledge exists, there are many persons or groups with capability to exploit the information, and thus the real critical path to innovation is more likely to be the knowledge pool than any particular entrepreneur.

The knowledge pool is developed through non-mission-oriented research in a range of fields 'by many different organisations'. Successful innovations tend to be preceded by *'unplanned confluences* of technology from different fields' (Kostoff; 1994, p. 61). In fact, the unplanned is combined with the planned: 'mission-oriented research or development stimulates non-mission research to *fill gaps* preceding the innovation'.

The second critical condition is *recognition of technical opportunity and need*. 'In many cases, knowledge of the systems applications inspires the sciences and technology that lead to advanced systems.' The second factor suggests that there is feedback on problems between of application engineers and scientific investigators. Radar, for example, was 'invented' in response to a clear need.

The third, fourth and fifth critical factors are a technical entrepreneur who champions the innovation; financial input; and management support. The sixth and final factor is *continuing innovation and development across many fields*. In the words of Kostoff: 'additional supporting inventions are required during the development phase preceding the innovation'.

Three of the six critical factors for success point to networking capabilities. From that perspective, an industrial district, unlike any single firm, offers the potential of a technological full-house with a variety and range of research-and production-related activities which can foster creativity, fill gaps, replenish the knowledge pool, link needs to research and incite unplanned confluences of technologies.

Complex system products

To contribute to economic growth, technologies must be embedded in production systems. The process by which technological capabilities are embedded in a company and a region's production system is an extension of the ongoing operations of entrepreneurial firms. The technology capability and market opportunity dynamic that drives the entrepreneurial firm is, simultaneously, a single step in a *cumulative* sequence by which a region's technological capability is extended.

The notion of the collective entrepreneurial firm extends to the region the technology capability and market opportunity dynamic that drives the growth of the firm. Regions can be thought of as developing specialised and

distinctive technology capabilities which give them unique global market opportunities. The successful pursuit of these market opportunities, in turn, reinforces and advances their unique regional technological capabilities. Regional specialisation results from cumulative technological capability development and the unique combinations and patterns of intra- and inter-firm dynamics that underlie enterprise and regional specialisation.

Thus, a region's technological capabilities are an outcome of a cumulative history of technological advances embedded in entrepreneurial firms. But the historical process is also *collective*. Just as individual entrepreneurial firms develop unique technological capabilities, a virtual collective entrepreneurial firm advances a region's unique technological capabilities. The regional process of technology capability advance will likely involve a succession of firms, with new firms building on advances made by previous innovators.

A region's technological capabilities are like a seabed, or an industrial ecology, in which entrepreneurial firms are spawned, grow, flourish and die. At the same time, however, entrepreneurial firms, driven by a technology capability and market opportunity dynamic, are forever advancing their own capabilities. In the process, the region's technological capability seabed is revitalised by the ongoing self-organising activities of its inhabitants. It is a virtuous circle. Regional technological capabilities spawn entrepreneurial firms, which upgrade regional technological capabilities, which spawn more entrepreneurial firms.

Specialised and cumulative regional technological capabilities lie behind the competitive advantage of 'low-tech' high-income industrial districts common to the 'third Italy'. Such districts have developed a competitive advantage in design capabilities that have fostered industrial leadership in a range of design-led or 'fashion industries'. But beneath such design capabilities is a unique mastery of a range of technologies derived from a craft heritage combined with specialist engineering skills.

Massachusetts is remarkable for its extraordinary depth and continuity of technological innovation capabilities. It is part of a region that has been on the cutting edge of new technology development since industry began in America. The processes of technological capability development and diffusion, however, are obscured by the conventional linear conception of technology diffusion from university research to company R&D to NPD. This is doubly so in Massachusetts because of the region's renowned research universities. The region's university research laboratories have an unrivalled record as a generator of techno-entrepreneurs and business spin-offs. But the headlines generated by individual success stories obscure the region's unique technological capabilities cumulatively and collectively embedded in its production system. The success of New England in jet engine production, for example, has a technological genealogy that goes back to water turbine innovations in the 1850s to power the region's textile mills.²⁴ The continuity of technological capability is deeply intertwined with the region's extraordinary innovation record and is crucial to an understanding of the region's economic growth and productivity level.

If the production system that defines the regional competitive advantage of the American mid-west is mass production, the production system that defines the competitive advantage of New England could be called complex system products. I look next at its technological heritage in the region.

Technological Heritage

New England's competitive advantage does not lie in mass production of consumer goods. New England has a regional competitive advantage in the manufacture of *industrial* machines, equipment and instruments.²⁵ Industrial and commercial machinery (including computers), and electronic and electrical equipment (including telecommunication exchanges and switches, electricity transformers, chip-making machines, air traffic control systems, electro-medical devices) account for close on half of the region's exports. That share goes up to 75 per cent by adding in instruments, engineering chemicals and transportation equipment (primarily aircraft engines and parts) (Little, 1993, p. 9). Some refer to these as the high-tech industries. They are equally representative of the precision equipment industry, which utilises the region's production capabilities in precision machining and technology integration. The manufacture of precision equipment, including instruments, machines, and tools, is a critical input to *complex system products*.

Complex system products tend to stay in New England. New England's competitive advantage in complex products springs from several factors. First, Massachusetts has long enjoyed a world-class precision equipment-making capability made up by hundreds if not thousands of firms collectively making a range of products from turbines to jet engines to printing machines to telecommunication switching equipment to semiconductor-making equipment. The heritage of specialist machine shops, tooling companies, instrument makers, equipment manufacturers and injection moulders collectively constitute a flexible open-system supplier base.²⁶ After a slow start, this supplier base has embraced information technology in the form of computer-aided design to compress the time to market for NPD (Forrant, 1998). The Internet has been a similar tool hastening the transition to process integration of the supply chain (the *kanban* system).

Second, the region has a long heritage in core industrial technologies. For example, innovation in turbine technology dates back to the early days of the Lowell textile mills, in the mid-1800s.²⁷ As in the cases of many complex products, aircraft engine making represents a product concept that had been initiated elsewhere but was turned into a production capability in New England.²⁸ Pratt & Whitney and GE often capture an 80 per cent market share of new orders for large commercial jet engines world-wide (Almeida, 1999, p. 3).²⁹

A leading post-war example is microwave technology, associated with the early development of radar in England. A team of scientists brought a single small magnetron (the microwave generating tube at the core of the machine) to the USA in 1940. Within five years a new industry had sprung up around

Route 128, creating the region's largest defence contractor, Raytheon, whose employment increased from 1,400 to 16,000 (Rosegrant and Lampe, 1992, p. 85). Raytheon developed lock step with MIT's Radiation Laboratory, set up in 1940 to co-ordinate microwave research. The Rad Lab, according to Rosegrant and Lampe (p. 84), developed over 150 systems 'that applied the versatile microwave technology to a dizzying array of applications'. The Greater Boston area may have been the only place where the capabilities and skills existed to ramp up a new industry so rapidly.³⁰

Third, the region has a heritage of links between instrument making, scientific research and new industry creation. The region's extraordinary instrument-making capability has been an important contributor to the region's strength in scientific research, and Rosenberg (1999) cites numerous examples of technological innovations precipitating such research. Sometimes, this feeds back to foster new industries.

The world's biggest scientific instrument is the Hale Telescope installed on Mount Palomar. Russell Porter, the principal designer, worked at the Jones and Lamson machine shop in Springfield, Vermont, in the 1920s, together with a journeyman machinist in optics and instrument design (Wicks, 1999). The owner, James Hartness, drew on Porter's knowledge of optics to devise more precise measures of screw threads, but saw the opportunities in lens grinding for instrument making. Sixteen machinists in the shop were members of the Springfield Telescope Makers in 1921. Most built their own telescopes, which required accuracy to one-millionth of an inch. These capabilities and skills contributed to the emergence of an optical cluster in Sturbridge, Massachusetts, led by companies such as American Optical Company. They also contributed to advances in the science of astronomy and, eventually, the marriage of optics and electronics and the development of electron microscopes.

Fourth, the region has an industrial heritage not only in precision machining technologies but in combining and recombining technologies to improve old or develop new products. The technology map of the jet engine, for example, is based on patent statistics involving twenty-four technical fields. These include aeronautics, ramjets and rockets, airfoils, optic systems, electro-chemical machinery, metallurgical apparatus and processes, measuring and testing technologies, fluid-handling systems, control systems, fuel systems, exhaust nozzles, coating and chemical processes and apparatus, and materials and materials manufacturing (Prencipe, 1998, table 1, p. 8).³¹

But even with all of these advantages, the severe downturn of the 1980s need not have been reversed. Critical to the resurgence in growth was the re-invention of many industrial sub-sectors and the creation of new sub-sectors in terms of systems integration.

Systems Integration

The application of design modularisation methodologies complemented the region's technological heritage. The combination of systems integration and

the region's unique production capability heritage in precision equipment may not have been planned, but it has been fortuitous. Systems integration is the great facilitator of the integration and re-integration of diverse technologies for the purposes of rapid NPD and innovation. The development of a regional capability to integrate information technology into the design, production and constitution of the product has been a source of competitive advantage. It has given leverage to the region's precision equipment and machine-shop heritage, forging a regional capability to combine and re-combine technologies in pursuit of new product applications.

The origin of systems integration in Massachusetts is the defence connection. Since the early 1950s, the Electronics Systems Centre of Hanscom Air Force Base in Massachusetts has co-ordinated a plethora of projects involving the integration of radar, communication, and computer and software technologies. Those projects were the foundation for America's air defence systems and air traffic control systems. Its digital computer sponsored project, known as Whirlwind, became the basis for the modern minicomputer, or business computer, which spawned Route 128's minicomputer giants such as DEC and Data General. The MIT Lincoln Laboratory, co-located with Hanscom, continues to specialise in radar, communications, digital processing, optics research and advanced electronics. In 1958 the non-profit MITRE Corporation was founded to focus on the 'systems engineering' requirements of air defense systems. The software challenges of systems integration are considerable, and Route 128 became a leader in developing computer-aided software engineering tools, user-interface design tools, advanced software design methodologies, and software testing tools (NCTP 1991, p. 55). This huge pool of software engineering talent fed back into the manufacturing base of the region to establish a unique capability for integrating hardware and software.

Integration of design and manufacturing

The defence connection and Massachusetts' industrial heritage, however, were not enough; systems integration as a driver of growth depends on the transition of a critical mass of industrial firms from sub-contractors to problem-solving enterprises with independent design and development capabilities. Rapid NPD depends upon a work organisation in which design and manufacturing are integrated. The hierarchical, functionally departmentalised, vertically integrated business model of New England that dominated during the Massachusetts' miracle years did not involve the decentralisation of design. The spread of the open-system business model was simultaneously about the development of high-performance work systems (HPWSs).

According to a recent report, the proportion of employees in firms that 'made some use of self-managed teams increased from 28 per cent in 1987 to 68 per cent in 1995'. 'A plant that has adopted a cluster of practices that provides workers with the incentives, the skills, and, above all, the opportunity to participate in decisions and improve the plant's performance has an

HPWS' (Appelbaum *et al.*, 2000, p. 9). The authors continue: 'Workers in an HPWS experience greater autonomy over their job tasks and methods of work and have higher levels of communication about work matters with other workers, managers, experts (for example, engineers, accountants, maintenance and repair personnel), and, in some instances, with vendors or customers' (2000, p. 7). New England was a leader in this transition.³²

It was a critical change in the organisation of New England business that facilitated the development of the new regional model of innovation. I turn next to skill formation, the third element in the productivity triad.

Technology skill formation

The open-system model of industrial innovation as pioneered in Silicon Valley and Route 128 in the USA involves tapping into basic research conducted at the region's universities. In fact, the co-existence of MIT and Route 128, and of the University of California at Stanford and Silicon Valley, has led many to identify research activities conducted in prestigious universities as the driver of knowledge-intensive industries. There is good reason. But it is not the whole story.

MIT set the standard. No other institution has played a more central role in producing techno-entrepreneurs and shaping new industries over a span of more than a century.³³ According to a BankBoston study,³⁴ MIT graduates have started 4,000 companies nationwide and 1,065 in Massachusetts; the latter account for 25 per cent of sales of all manufacturing firms and 33 per cent of all software sales in the state.³⁵

The close links between MIT's and Stanford's research capabilities and the high-tech enterprises around them are widely recognised. They have become models for policy makers the world over. Too often, however, the links between R&D conducted at research universities and industrial innovation and growth are defined in terms of a linear sequence model that obscures the underlying relationships. Dozens of prestigious universities located elsewhere are not associated with regional growth dynamics, just as most high-growth success stories do not involve a technology transfer role for prestigious universities.

The productivity triad and the capabilities and innovation perspective suggest a more complex set of relationships between basic research conducted at universities and industrial growth than the flow of technology and techno-entrepreneurs, important as they can be. Put differently, successful technology transfer, in terms of the growth process, is a consequence of three underlying and enabling relationships that are obscured by the linear sequence view:

- university research activities to assist the *technology-market dynamic* that drives regional growth dynamics;
- *manpower planning* processes to address the scale requirements of the growth process; and

- characterising and diffusing *engineering methodologies* to target technology transitions.

Enterprise capability–university research dynamic

Regional growth dynamic processes depend upon business models driven by the technology capability and market opportunity dynamic. The links between industrial innovation and productivity growth go beyond the transfer of new technologies from university labs, as important as that can be in special cases. Even in cases of successful technology transfer, the transfer is often a consequence of a mutual adjustment process driven by entrepreneurial firms with networking capabilities.

The rapid growth of entrepreneurial firms is simultaneously an advance in technological capabilities. The research capabilities and knowledge specialisation of universities may or may not be shaped by the unfolding process of unique technology capabilities of entrepreneurial firms, but the regional growth impact can be substantial (Best, 2001).

Such a mutual adjustment process between growing firms and university research capability development is critical to an understanding of both Silicon Valley and Route 128. Silicon Valley and Stanford, in the words of Leslie and Kargon (1996, p. 470):

had grown up together, gradually adjusting to each other and to their common competitive environment. Each helped the other discover and exploit new niches in science and technology . . . In the proliferation of new technical fields and new companies that characterised the early evolutionary stages of these industries, the right kind of university could make a real difference in fostering horizontal integration and collective learning throughout the region.

A failure to understand that dynamic is responsible for the nearly universal lack of success in transplanting the Silicon Valley model, even by Frederick Terman himself. Terman emphasised the crucial role of prestigious universities and their capacity to attract leading scholars, not the mutual adjustment processes identified here. Entrepreneurial firms in Silicon Valley, such as Intel, have benefited considerably from research activities at Stanford University, but these have been the outcome of the nurturing of networking capabilities over a period of time.

Thus, the impact of university research on growth will depend in important ways on whether regional innovation processes are underway. University research, alone, will not drive a region's business model or shape the level of technology management capabilities. As shown in figure 9.2, an open-system regional growth dynamic is also an enterprise startup system that multiplies the number of entrepreneurial firms and drives a set of innovation dynamics. A responsive tertiary education system is critical to fuelling those growth processes with the requisite skills.

Manpower development planning

Entrepreneurial firms are successful because they advance technology capabilities to develop emerging market opportunities in an ongoing interactive process. But sustained regional productivity growth depends upon more than technology transfer and absorption.

In fact, even the combination of right business model and specific technology capability development will not sustain growth. The growth of firms will not translate into regional economic growth without the expansion of the requisite engineering–technological skill base. The regional growth dynamics depend as well upon a labour pool of engineers and technologists to convert the innovative ideas into production capabilities. As shown in figure 9.3 the role of tertiary education is critical for producing a pool of engineers and technologists to convert innovative ideas sparked by the internal growth dynamic of entrepreneurial firms into viable products on the *scale* and in the form required for regional growth.

An inelastic skill base will translate into skill shortages and wage pressures thereby choking growth and eroding regional competitiveness. Industrial development depends upon this process of labour supply development. Without a complementary growth in a labour force with the requisite skills, the innovation capabilities even of MIT would not have been translated into sustained regional growth dynamics.³⁶

Figure 9.4 reveals an extraordinary supply response to the technology capabilities being developed during the Massachusetts’ miracle. The number of bachelor’s degrees in electrical engineering conferred by Massachusetts’ universities and colleges increased from 718 in 1982 to 1,648 in 1988. The costs of this transition were heavily borne by the public education system. An expansion in graduates by 1,000 requires an increased intake of 4,000 students

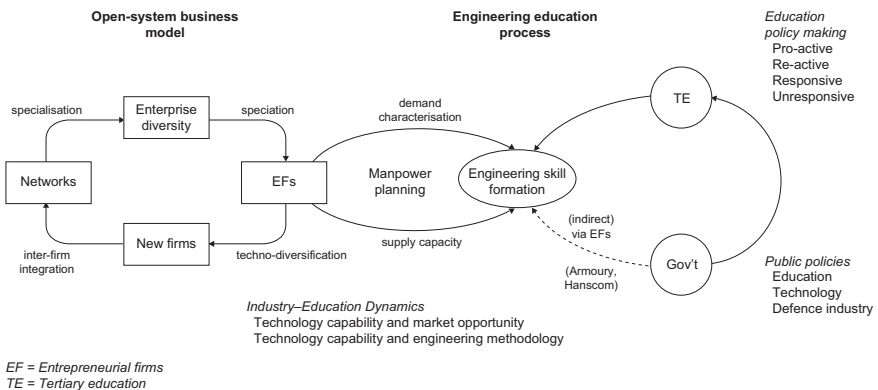


Figure 9.3 Regional growth and skill formation dynamics

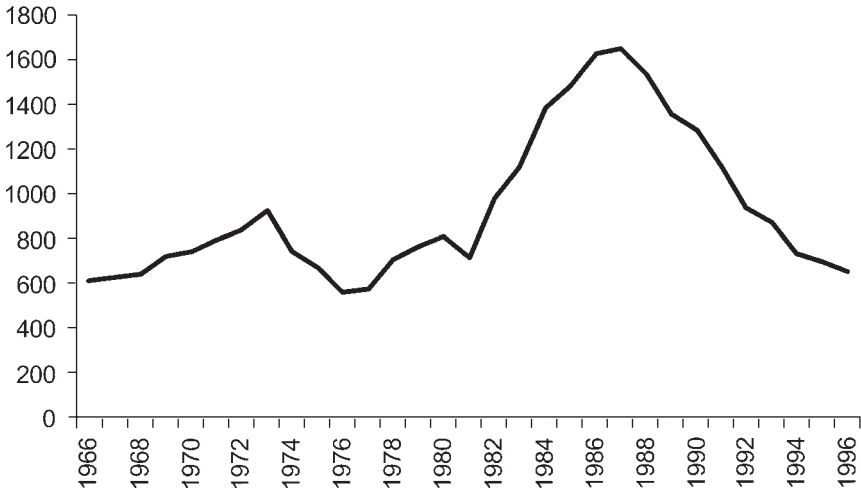


Figure 9.4 Electrical engineering graduates in Massachusetts

in electrical engineering degree programmes which, in turn, requires an expansion in faculty positions of nearly 300 (given a 15:1 student to faculty ratio) in electrical engineering, plus a corresponding investment in facilities.

The sharp drop-off that accompanied the crash of 1986–92 has not turned around. The resurgence relied heavily on skill formation investments by the educational system and human resource programmes of companies enacted during and preceding the miracle years. It has also relied on immigration. This is not always available.

The Massachusetts labour force benefits from roughly 15,000 immigrants per year. The proportion of the recent foreign immigrant population to Massachusetts in ‘highly skilled management, professional, and technical occupations’ is estimated to be 33 per cent. (According to the 1990 census, 28 per cent of the immigrant workforce in the state had a bachelor’s degree or higher (MTC, 1998).) In-migration has taken up much of the slack from the shortfall of engineering graduates of colleges and universities in the state. The number of foreign-born and, in most cases, foreign-educated technical workforce has accumulated to a sizeable fraction of the total pool.

Furthermore, the figure suggests another source of increased technical labour supply in Massachusetts: graduates who remain in Massachusetts. Of the 6,000 graduates produced per year, a higher percentage stays in the state. The trend in net migration over the ‘resurgence’ has shifted from minus 60,000 to plus a few thousand. If this trend line continues and the international in-migration stays constant at roughly 5,000 per year, Massachusetts goes some distance to responding to the needs.³⁷ Here, again, the Massachusetts education system is supplying benefits that impact on growth.

Engineering methodologies and curriculum development

Integral to the notion of the productivity triad is the process of mutual adjustment between technology advancing, rapidly growing firms which, in fact, are driving a new technological trajectory, and engineering methodologies which make it possible to ramp-up an engineer–technologist skill base. These form a mutually interactive process in which technology capabilities in companies and engineering methodologies in the education system march forward together. This is particularly so with the application of the principle of systems integration and the development of the open-system business model that has opened up the terrain of knowledge-intensive industries.

This regional dynamic did not begin with MIT. Engineering disciplines are not static. As we have seen, precision engineering has been re-invented in each major technological era beginning with the mechanical age and extending into photonics and genome technologies. Each technological age has been accompanied by the development of a new engineering discipline that, in turn, became a vehicle for the diffusion of the new technology across the industrial spectrum. In the early days the agents of diffusion were machinists trained in interchangeability or, ‘armory practices’ – a term denoting the organisational capabilities that accompany and institutionalise the technical aspects of interchangeability (Best, 2001, pp. 25–8). Today they are likely to be engineering and science graduates who have specialised in disciplines such as information technology, opto-electronics (photonics) or life sciences. Here, too, New England has a rich heritage that fits both the continuity and change dimensions of technology.

MIT has been closely involved with industry-leading entrepreneurial firms.³⁸ But those linkages play a role in the development of an engineering curriculum that makes it possible to ramp-up skill bases to supply the needs of regional concentrations of industry and rapid growth. Examples include chemical engineering, and the chemical and then petro-chemical industries; electrical engineering followed by the electrical power and electric engineering firms such as GE; microwave technologies and the development of Raytheon. In all of these cases, the development of the technology and the industry-shaping and market-creating and expanding firms was not university technology spin-offs but partnerships in the co-shaping of emerging and unfolding technologies and engineering methodologies.

Systems engineering does not fit neatly into the educational curriculum, but is nevertheless critical to Route 128’s competitive advantage. The region’s heritage in complex system products is important here. Systems integration activities demand an ability to communicate across technological domains.³⁹ Complex system products are training grounds for systems integrators, individuals who can speak in several technological languages.⁴⁰ New England has a high share of cross-technology communicators. With each historic development of new engineering methodology the earlier ones were redefined to make them interoperable. Mechanical became electro-mechanical followed by integration with electronics and, later, information technology. Information

technology plays a double role as independent technology domain and enabler of technology integration. Each revolution fostered a regional ability to communicate across technological domains. Most techno-entrepreneurs are cross-walkers – problem-oriented people who learn to read and converse in diverse technological languages. These are the vaunted communication skills that are often considered missing in engineering education.

The formal education system was of vital importances, but so too was the codified and tacit knowledge that was created in the process of pursuing the technology capability–market opportunity dynamic that defines the entrepreneurial (learning) firm. While the vertical integration business model became a drag on the region’s innovation potential, it contributed to the development of a deep and broad skill base in systems integration. Together the enterprise and educational system dynamic bequeathed to the region a skill base in systems integration activity highly appropriate to the requirements of the new industries following upon the information technology revolution. If those skills had not been bequeathed from an earlier period, the region would have had to create them anew.

Conclusion

The development of competitive advantage in high technology in Massachusetts is as much about technological continuity as it is about change. The region’s traditional technological capabilities in precision machining, complex system products, and science–engineering education positioned it well for the minicomputer and defence industries that grew rapidly during the period of the Massachusetts’ miracle. Furthermore, there was a logic to the vertical integration business model that drove growth during these years. In both product areas, the business model reinforced integral or closed-system architecture. Design modularisation was not the challenge. It was only with the development of design modularisation elsewhere that the combination of a vertically integrated business model and an integral product architecture common to Massachusetts’ was no longer viable.

The application elsewhere of the open-system business model of focus and network-fostered regional innovation and regional growth dynamics opened up a new regional competitive advantage. In the new model, business and industrial organisation were redefined to capture more fully the innovation and growth potential of systems integration and the associated decentralisation and diffusion of design.

But New England enjoyed two of the three elements of the productivity triad for systems integration.⁴¹ From that perspective, the secret to the success of the resurgence was the transition from a vertically integrated closed-system business model to a focus and network model based on open systems at the technological and organisational levels. The challenge of design modularisation was met with the development of open-system architecture and standard interface rules.

Silicon Valley was the first to apply the principle of systems integration at both the technological and business model levels, thereby to institutionalise a new model of technology management. The irony is that systems integration has long existed in New England but as an engineering skill and technological capability, not as a unifying principle of production and business organisation. But systems engineering and systems integration as technological capabilities were confined largely to a closed-system architecture.

Silicon Valley demonstrated that a focus and network business model could drive the new innovation forces and convert them into a new competitive advantage. The development of the Internet as an open-system information highway was itself a paradigm example of the advantage of standardised interface rules and an enabler of specialist companies to plug into value networks.

Silicon Valley, as 'new competition', forced a wave of Schumpeterian 'creative destruction' across New England businesses. The region's sharp economic decline played a major role in explaining the timing and wide diffusion of the transition from the closed-system to the open-system business model. The severity of the industrial decline that ended the miracle years had two effects: widespread business failure involving companies organised according to the dictates of vertical integration and the release of a huge labour pool of those educated and trained in systems integration skills. The new business model depended on a supply of skilled labour. Without this pool the regional growth dynamics illustrated in figure 9.1 could not have driven sustained economic growth. Such growth would have been choked by technical skill shortages.

The skills in the labour pool and the technological capabilities that Massachusetts' enterprises had built over generations did not go away. They resurfaced in new firms, new products and new applications. But, most importantly, they eased the transition to a new open-system business model, a model more appropriate to exploit the opportunities offered by systems integration at the technological level.

The new open-systems business model advances two performance standards which are crucial to competitive advantage in New England, rapid NPD and disruptive innovation (as distinct from incremental innovation). The region's machine shops facilitated the rapid diffusion of systems integration. The job-shop heritage complemented a major dimension of systems integration, namely the capability to redesign the whole to take advantage of design changes in component parts, or modules. The region's custom design heritage in machines and tooling was re-invigorated. Design was again important. But it was now integral to the region's business model.

The open-systems business model made possible the full set of regional growth dynamics captured in figure 9.3. Now firm and inter-firm technology development teams could be formed and reformed in pursuit of the new opportunities emerging as a by-product of the techno-diversification process. It was an ideal fit for Massachusetts.⁴² It has re-invented manufacturing in the region.⁴³

The techno-diversification of Route 128 is itself a consequence of the conversion of systems integration from a technological to a business and

industrial organisational capability. The conversion can be understood in terms of the diffusion of the new model of technology management, the establishing of a complementary business model capable of driving the new principle, and an advanced, diverse, flexible and targeted skill base. Industrial policy also played a key role, if inadvertently.

In fact, this specific industrial heritage turned out to be an ideal infrastructure for information technology. New England's heritage of complex systems product turned from a disadvantage in the age of consumer electronics and incremental innovation to an advantage in the age of information technology and disruptive innovation. Consequently, the region has been a major beneficiary of the information technology revolution.

In a sense the resurgence has been about the reinvention of a regional industrial system to fully exploit the opportunities inherent in the emergence of a new technology. As Ford had used electricity to redesign the manufacturing plant to apply the principle of flow, New England has, in effect, used information technology to redesign the region's industrial capability to apply the principle of systems integration. But, ironically, complex system products are in many ways a better production platform for the technological management of disruptive innovation than is that of mass production.

In conclusion, both the decline and the resurgence of Route 128 can be explained in terms of the emergence of a new competitive advantage based on the principle of systems integration which has both fostered and been driven by a comprehensive re-organisation of the business system. An open-system model of specialist and networked firms has transcended the old closed-system vertically integrated business model. The principle of systems integration, like all principles of production, is expressed technologically, organisationally (business model) and in engineering methodology (technical skill requirements and educational capability). The new business model involves a strategy of focus and networking, and an organisational structure of decentralised, diffused and complementary design capabilities across a wide range of business enterprises. The result has been a regional capability to rapidly create, develop and commercialise new product concepts, to re-invent products, diversify technologies, create new market niches and invent new industrial sub-sectors. These processes are part of a new regional decentralised–distributed model of innovation. An understanding of these processes holds the key to understanding the resurgence of growth in Massachusetts.

Notes

- 1 This chapter draws on material published in Michael H. Best, *The New Competitive Advantage: The Renewal of American Industry* (2001).
- 2 Symbolic of the decline was the sale of the Wang Towers in Lowell, Massachusetts, for \$500,000 in 1992, a building complex that had cost \$80 million to construct during the period known as the 'Massachusetts' Miracle'. In April 1998 Wang Towers, then home to thirty-five companies, sold for \$120 million.

- 3 Deming (1982) and others use the term ‘white spaces’ to denote the space between the boxes in the organisational charts of functionally departmental enterprises.
- 4 The term ‘technology–market dynamic’ is a version of Penrose’s productive capability/market opportunity dynamic (Penrose, 1995). The idea of the entrepreneurial firm as an extension of the entrepreneurial function from an individual attribute to a collective or organisational capability is developed in Best (1990).
- 5 A closed architecture is one that cannot accommodate components with independent design rules. It means, for example, a computer that will perform word-processing only with a software programme that is co-designed with the computer. Wang wordprocessors did not run *Word* or *WordPerfect*.
- 6 See Morris and Ferguson (1993) and Garud and Kumaraswamy (1993) for detailed examples.
- 7 For an elaboration of table 9.1 see Best (1998).
- 8 Chandler (1977) describes the development of the central office–functionally departmentalised business model as an organisational structure established to pursue the business strategy of vertical integration. The vertical integration organisational structure was particularly appropriate to achieving high rates of ‘throughput’ or ‘economies of speed’, both measures of flow. But it was more effective under conditions of technological stability.
- 9 A leading example is Intel. Intel’s ‘dynamic dialectic’, as described by co-founder Andrew Grove (1996), is designed to combine recurrent phases of bottom–up experimentation and top–down direction. Phases of experimentation, which stimulate new ideas and innovation, are fostered by decentralisation of decision making. The challenge of leadership is to allow enough time for free rein to stimulate the development of new ideas before managing a new phase during which the most promising ideas are pursued and the weaker ideas are abandoned. The challenge of leadership is to balance the phases of experimentation and direction so that the enterprise can benefit from the advantages of both bottom–up initiatives and top–down decision making. Too much experimentation can result in chaos; too much direction can stultify innovation. Built into the challenge of leadership is a requisite ability to manage organizational change; leaders must gain personal commitments to new directions, technologies, processes and products. Without personal commitments from top to bottom, human energies will not be mobilised to drive the redirection of organisational resources. While experimentation requires everyone to act as designers, direction demands that everyone enthusiastically accept the winning designs. This is no small organisational challenge.
- 10 The cluster dynamics model and its genealogy in the history of economic thought can be found in Best (1999).
- 11 Different models of innovation are explored in Best (2001).
- 12 The companies are ArrowPoint Communications, Inc., of Westford, Astral Point Communications of Westford, Cadia Networks, Inc., of Andover, Castle Networks, Inc., Convergent Networks of Lowell, Equipe Communications of Acton, Ignitus Communications of Acton, Omnia Communications, Inc., of Marlborough, Redstone Communications of Westford, Sonus Networks of Westford, and Sycamore Networks, Inc., of Chelmsford.
- 13 Massachusetts had 6.2 million people in 1999, 2.3 per cent of the USA’s total.
- 14 The firm faces a dilemma: unique capabilities are both the source of competitive advantage and a constraint on future development. Firms that experiment and develop unique and/or new capabilities simultaneously must choose which of the

new possibilities to pursue as the basis of their competitive advantage. Given the inherent uncertainty regarding technological change, firms are required to place bets on which technological possibilities should be pursued and which abandoned. No firm, no matter how big, can pursue all technological possibilities. New opportunities, which require activities that are not consistent with reinforcing the firm's basic position, risk devaluing the firm's unique capabilities. Those not pursued internally become 'market' opportunities for other firms to advance their productive capabilities.

- 15 Each of these processes contribute to *potential* regional techno-diversification which, if activated, can trigger industrial 'speciation' or the emergence of new industrial sub-sectors (more on this in the next section).
- 16 Externally integrated enterprises are defined as productive units co-ordinated within 'closed-system' inter-regional networks or value chains directed by global enterprises.
- 17 Horizontal integration, the term used by Andrew Grove (1996) to describe open-system networking, can be considered an inter-firm consequence of Intel's production concept of integrated manufacturing (see Best, 1998).
- 18 The regional model of innovation offers a decentralised, self-organising explanation of the success of high-tech regions as an alternative to the linear science-push model of innovation. In the science-push model, technology is thought of as applied science; in the regional model, technology is part of the industrial process. It is built into the process by which firms establish unique capabilities and network with other firms. The science-push model, in contrast, fails to capture the extent to which research is woven into the production, technology and networking fabric of a region's industrial system as distinct from being an external autonomous sphere of activity.
- 19 Intel is not the only driver of new products. Approximately one in five of the Silicon Valley (and Route 128 in Massachusetts) publicly traded companies were 'gazelles' in 1997, which means they have grown at least 20 per cent in each of the last four years (the number for the USA is one in thirty-five). See Massachusetts' Technology Collaborative (1998).
- 20 The technology capability and market opportunity dynamic which drives the entrepreneurial firm has an analogous technology and market dynamic that operates at the regional level. This is a *collective* entrepreneurial capability. It underlies and explains a region's clusters.
- 21 See Best (1990, pp. 207–8).
- 22 The regional innovation processes can be referred to as the 5Ds: disruptive (internal–internal dynamic), dip-down (fast new product development), design diffusion (leveraging creativity), dispersed (laboratories for experimentation) and diversity (new technological combinations).
- 23 See Katz (1996, p. 15). Katz also describes network economies and increasing returns.
- 24 James Francis's early experiments in turbine technology were conducted at the Wannalancit Mill.
- 25 In contrast, the American mid-west developed a regional technological capability and competitive advantage in mass production. In both cases the regional technological capability can be expressed in a wide range of final product areas. But, at the same time, regional technology capability is itself an expression of the cumulative dynamics of a region's production system.

- 26 The largest manufacturing sectors in Greater Boston in the mid-1990s in employment were instruments (35,000), industrial machinery (23,000), printing and publishing (22,000), electrical equipment (21,000) and fabricated metals (11,000) (Terkla, 1998, p. 15).
- 27 Turbine technology was originally developed in New England as part of the system of canals and locks built to power the Lowell textile mills. James B. Francis, designer of the system of locks and canals that powered the Lowell textile mills, was an innovator in water turbine technology.
- 28 Precision machining is equally encoded in the aircraft engine industry's technology. The Pratt & Whitney Machine Tool Company was established as an armaments' maker in 1860. Both Pratt and Whitney had been employees of the Samuel Colt Armoury which itself had links with Eli Whitney, a controversial figure in the development of interchangeability. Frederick Rentschler, former president of Wright Aero, was looking for a site to develop air-cooled radial engines for the US Navy. He went to Hartford and leased the rights to use the Pratt & Whitney name and located in empty space in Pratt and Whitney's machine shops. His design concepts were translated into a functioning engine and within three years the Pratt & Whitney Aircraft Company was an enormous success. Pratt & Whitney went on to produce close to half the total aircraft engine horsepower produced in America during the Second World War. GE developed the jet engine in Lynn, Massachusetts (see Almeida, 1999).
- 29 Jet engine production is not in principle different from car engine production but it inevitably requires more stringent testing of technological modification in any part on the performance of the whole, including the aircraft, under all types of conditions. In this respect, jet engine production is not intrinsically different from microprocessor production. But if jet engines were produced to the yield rates of the best chip-making fabs in the world, the airline industry would not be feasible. The combination of rigorous performance standards and interactive feedback effects presents stern engineering challenges of an order of magnitude higher than those of both car and microprocessor production.
- 30 The innovation potential which attracts firms from around the world into Massachusetts is based on the skill base, the diversity of technologies which are potential inputs to systems integrators, and the time compression facilitated by the wide and deep supply base for engaging in NPD. For example, Michel Habib, Israel's economic consul in Boston, estimates that the number of Israeli technology firms in the Boston area grew from thirty in 1997 to at least sixty-five in early 1999. The companies span a range of technologies, including optical inspection machines, medical lasers, digital printing equipment, scanning technology and bio-tech. In the words of one Israeli manager, 'There are a lot of technological resources and knowledge in the area we can take advantage of' (Bray, 1999).
- 31 An aircraft engine involves extremely precise tolerances, and this has in turn, fostered sustained technological advances in lightweight materials, super alloys and parts' fabrication. These all belong to the collective entrepreneurial firm and market opportunity dynamic which underlies the development of regional competitive advantage.
- 32 In early 1990, seven Boston-area companies formed the Center for Quality Management to work together in TQM (total quality management). It became a model for rapid application and diffusion of continuous improvement work organisation. The Center identified 135 kinds of diffusion channels (Shiba, Graham and

- Walden, 1993). See Forrant and Flynn (1998) for a case study of making the transition to a high performance work system.
- 33 MIT's role in America's first high-tech industrial district inspired Frederick Terman, a dean of engineering at Stanford, to plant the seeds for a west coast high-tech version. He persuaded administrators to establish the Stanford Industrial Park and two of his students, William Hewlett and David Packard, to set up shop there. Another early occupant was Xerox's Palo Alto Research Center the site of a series of innovations that came to constitute the personal computer (Cringely, 1992). Sun Microsystems, Silicon Graphics and Cisco Systems are but three other examples whose origins can all be traced to Stanford's classrooms.
 - 34 See MIT's: The Impact of Innovation website at <http://web.mit.edu/newsoffice/founders>
 - 35 According to *Mass High Tech* (17(38). 1999. p. 23), the software industry of Massachusetts is driven by '... small firms founded by former executives who have cashed out before, or by recent graduates of the area's top engineering schools'.
 - 36 Cambridge University researchers have developed many innovations, often in partnership with industrial labs and emerging companies. Rarely have these developments been translated into regional industrial growth. The development of engineering methodologies must involve methods for ramp-up in technical labour supply and the institutional capability to drive it. It is as if Cambridge, Massachusetts, has had manpower planning capability and Cambridge, UK, has not.
 - 37 The figures on international and domestic migration for Massachusetts, 1991–98, are given in Massachusetts Technology Collaborative (1999, p. 41).
 - 38 No other institution has played a more central role in the process of growing techno-entrepreneurs and shaping entire new industries over a span of more than a century. According to a study by the BankBoston economics department, MIT graduates have started 4,000 companies nation-wide. In Massachusetts, the 1,065 MIT-related companies account for 25 per cent of sales of all manufacturing firms and 33 per cent of all software sales in the state. See MIT's The Impact of Innovation website at <http://web.mit.edu/newsoffice/founders>
 - 39 In Richard Adams's *A Hitchhiker's Guide to the Galaxy*, a 'Babelfish' device is placed in the ear to enable communication across inter-galactic languages. Technology integration requires a capacity to communicate across technology language fields (see Adams, 1989).
 - 40 Machine shops require language capabilities in software, and mechanical and electrical engineering.
 - 41 As noted above, the productivity triad is a form of systems integration. All three elements (business model, technology management capability, and specialist engineering skills) must be in sync for a region to benefit in the form of regional growth from technological advances. This observation goes some way towards explaining the 'productivity paradox', Robert Solow's observation that computers have shown up everywhere except in the productivity figures. Ditto the case (examined above) of electricity: advances in the application of electricity showed up years after its discovery when Ford used distributed power to redesign the production process according to the logic of flow (Best, 2001).
 - 42 A company engaged in the manufacture of complex system products enjoyed the advantage of the flexibility of a job shop but lacked the efficiency of flow systems. But the mass-production systems are not designed to pursue the technology capability–market opportunity dynamic with the same degree of flexibility for

incorporating disruptive technological change as the 'open-systems' business model. In this sense, New England perhaps has gone further than Silicon Valley in establishing a complex system products business model as distinct from flexible mass production (lean production). By the integration of software and hardware, job shops that were organized hopelessly according to the dictates of world-class manufacturing found a new business model by which they could pursue a strategy of rapid NPD on technological systems integration.

- 43 The new business model, one of regional innovation, is simultaneously a technology management capability for rapid NPD. It is driven by competition over the rapid development of new product concepts which, in turn, thrives on the dip-down model of innovation. This business system pulls in, and integrates, basic research with the manufacturing processes.

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