# The Capabilities and Innovation Perspective: The Way Ahead in Northern Ireland

by

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with

**A Statement by the Economic Council**

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# 1. INTRODUCTION

The Northern Ireland Department of Education conducted a survey of the 225 students who qualified in electrical/electronic higher education courses in the academic year 1996/7. Only 25% were working as electrical and electronics engineers *within Northern Ireland*.[1] This statistic is like an economic thermometer measuring the health of the patient. Engineering/science graduates are the high-energy fuel that propels high industrial growth rates.[2] Unable to absorb advanced technological skills, it is not surprising that the Northern Ireland economy suffers from low productivity, lack of innovation, and slow growth.[3] It is like a patient suffering from diabetes, unable to absorb glucose.

The agent of technological change is the business enterprise. If the technically educated graduate is the high-energy fuel for growth, the engine is the *entrepreneurial firm.* The lack of demand for engineering/science graduates by business enterprises in Northern Ireland is a manifestation of the deep source of poor economic performance in the region: its business model. Northern Ireland lacks entrepreneurial firms.

The fate of Northern Ireland's economic future depends upon the struggle between two business models. One enables firms to pursue an entrepreneurial, proactive, product-led business strategy. The other consigns firms to a non-entrepreneurial, reactive, price-led business strategy.[4] The first represents the 'New Competition' and the new economy, the second is rooted in the old competition and the old economy.[5] Fortunately, Northern Ireland does have entrepreneurial firms. But it has far too few.

Entrepreneurial firms negotiate the integration of technology into production and thereby enhance the productivity of labour and capital by the development of production capabilities. Three technology-progressive features of entrepreneurial firms can be distinguished. First, entrepreneurial firms are the agents of the technology capability and market opportunity dynamic. They develop and host unique regional technological capabilities. Second, entrepreneurial firms are the initiators of cluster growth dynamics that, in turn, foster a range of

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1 *Department of Education (Northern Ireland), cited in Sector Working Group on Electronics Final Report (1998:13), http://www.Strategy2010.com.*

2 *The term high-energy fuel refers to the critical role of technology as a determinant of growth. The theoretical challenge has been to make technology endogenous to growth theory (see Lipsey, 1993). The capabilities and innovation perspective anchors innovation and technological change in the growth dynamics of the business enterprise.*

3 *Productivity levels are low by standards in the United Kingdom, which, in turn, are 20-40% below those in the United States and leading European economies (DTI, 1998: Chart 3.11). See Hitchens et al. (1991) for a matched plant comparison which suggests that productivity in Northern Ireland manufacturing plants was roughly half that of their West German counterparts in the 1980s. A recent survey of innovation expenditure as a share of total expenditures was reported to be 2.5% in Northern Ireland while the UK average was close to 7% (http://www.cbi.uk/standard/its/graphicgs/exhib37.htm).*

4 *Enterprises that pursue a reactive business strategy are price-taking not price-making; product-taking not product-making; technology-taking not technology-developing; and market-taking not market-creating. The business model challenge in Northern Ireland is exacerbated by government subsidisation of business. High subsidisation has contributed to a state-dependent business culture.*

5 *These distinctions are developed in Best (1990).*

technology advancing processes. And third, entrepreneurial firms pioneer systemic advances in production capabilities, one of which is technology management.

Technology management capabilities at the enterprise and regional levels can be powerful levers for growth. Technology management institutionalises processes by which a firm and a region can leverage the world's technology pool on an ongoing basis. The term technology management captures the capability aspect of technology; technology is embedded in production capabilities.

Skill formation goes hand-in-hand with the advance of a region's entrepreneurial firms. As enterprises develop *capabilities* for new product development, technology management, technology transition, innovation, and networking, for example, they employ or access engineering/science skills and integrate them into their production operations. The lack of demand for such graduates is a reflection of the lack of capability development in Northern Ireland business enterprises.

At present, Northern Ireland lacks agents of transition to the New Competition at both enterprise and government level. Few firms pursue product-led business strategies and develop the enabling production capabilities. Industrial policy in Northern Ireland seeks, on paper in government strategy documents, to build a new economy but its actions reinforce the prevailing, reactive business model. The problem is not lack of funding. Enterprises are highly subsidised. In fact, regional assistance to Northern Ireland manufacturing enterprises regularly funds between a third and a half of net capital spending.[6] But large subsidies have not been catalysts for innovation, capability development, skill formation, technology management, or regional growth dynamics.

Policy-makers must decide which industrial policy to pursue: reinforcement of the old industrial order or transition to the New Competition. It cannot do both. Only an industrial policy which facilitates the development of the capabilities which constitute entrepreneurial firms and cluster dynamics offers the potential to advance the region's competitive advantage in high value added activities. The failure to absorb three-quarters of the region's technically educated graduates suggests that, at present, a regional competitive advantage is not being developed in knowledge-intensive sectors and activities, at least on any significant scale.

The challenge for policy-makers is to assist a transition to a higher performance economy. The purpose of this Report is to lay out an economic perspective to guide policy-makers. The capabilities and innovation perspective focuses attention on the dynamic processes that drive rapid growth. An understanding of these processes is critical to designing effective industrial policies.

Chapter 2 elaborates the agents for change and growth dynamics from the capabilities and innovation perspective. The technology and market dynamic of entrepreneurial firms and inter-firm dynamic processes that underlie high productivity clusters are elaborated.

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6 *Regional assistance as a percentage of net capital expenditures for manufacturing in England, by contrast, has declined from 3% to 1 % between 1988 and 1995. See NIEC (1999b: 18) and Chapter 4 below.*

Rapid growth involves coordinated organisational changes in each of three domains: the business model, production capabilities, and skill formation. The concept of a *Capability Triad* captures the systemic dimension of organisational change at enterprise and regional production levels. The three domains are not separable and additive components of growth but mutually interdependent sub-systems of a single developmental process. The intersecting circles (business model, production capabilities, and skill formation) in Figure 1 express visually the idea that no one of the three elements of the Capability Triad can contribute to growth independently of mutual adjustment processes involving all three elements.

In Chapter 3, the capabilities and innovation perspective is applied to Northern Ireland. Firms, government bodies, educational institutions, research centres, and mission-driven agencies were visited to make qualitative assessments of capability and innovation indicators (see Appendix 1).[7] The purpose of company visits is first, to compare a region's business enterprises against international benchmarks in terms of capabilities and, second, to identify existing, emerging, or potential entrepreneurial firms, the drivers of regional growth. These visits drove home the chief conclusion of this report: the major barrier to growth in Northern Ireland is its business model. The challenge of making a transition to a new business model, however, is not limited to the internal organisation of business enterprises.

Chapter 4 turns to industrial policy. Unintentionally, industrial policy has preserved the old order. Five challenges to making the transition to the New Competition and a high growth scenario are presented. The chapter concludes with ten policy implications.

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[7] *The author has had twenty years' experience of visiting production facilities in many parts of the world. The production capabilities spectrum outlined in Chapter 2 offers an international criterion for assessing a company's production capabilities. More formal assessment criteria associated with the quality movement can provide more quantifiable measures but are less useful for assessing the dynamic processes also outlined in Chapter 2.*

## 2. THE CAPABILITIES AND INNOVATION PERSPECTIVE

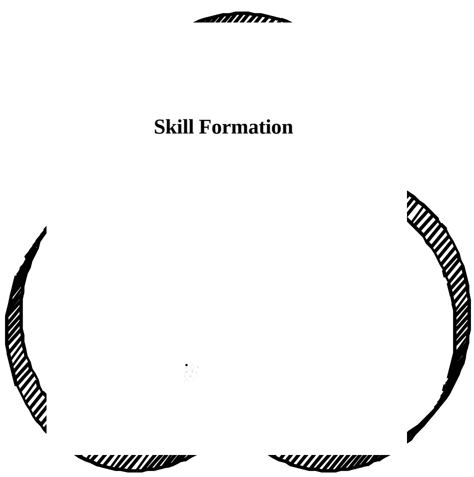
How can regional policy-makers foster rapid industrial growth? In the case of Northern Ireland the challenge is less than elsewhere. Northern Ireland has unrealised growth potential in its technical skill base. The operative question is what changes in business organisation are needed for Northern Ireland to be able to absorb 100% of the engineering/science graduates in activities that directly use and advance their skills? The demand for technical graduates is a function of the pace of technological change in a region's business enterprises. This is the domain of technology management at the levels of the enterprise and of clusters or networked groups of enterprises.

Unfortunately, technology management is neither a free good nor purchasable in the market-place. Rather, it is a capability embodied in and amongst business enterprises and partner institutions. Advancing technology management capabilities at both the regional and enterprise levels are significant organisational accomplishments that underlie the industrial development process. Properly targeted industrial policy can play a critical role in influencing the development of technology management capabilities and, thereby, the pace of technological change.

The conceptual challenge is to make links between the internal dynamics of entrepreneurial firms and the growth of the regional economy. Growth can be divided into two components. The first is the contribution made by increases in the number of people in the labour force. The second is productivity growth (i.e. output per worker) which comes from advances in production capabilities, including technology and skills. The goal is to grow by increasing productivity as this increases per capita income. A tenet of the capabilities and innovation perspective is that technology-led growth involves *synchronised* advances in business organisation, production capabilities, and skill formation. These three elements form the *Capability Triad* represented in Figure 1.

**FIGURE 1**

**Capability Triad**



Sustained and rapid growth is about mutual adjustments involving all three elements.[8] Upgrading skills, for example, will not translate into regional growth unless the skills are shaped and reshaped as part of a mutual adjustment process with a region's production capabilities and entrepreneurial firms. Skill upgrading, production capability advance, and enterprise growth are mutually interactive in technology-led growth experiences.[9] Each of the three elements of the Capability Triad is examined in this chapter. We then draw implications for rapid growth scenarios. The challenges for industrial policy then come into focus.

**Business Model**

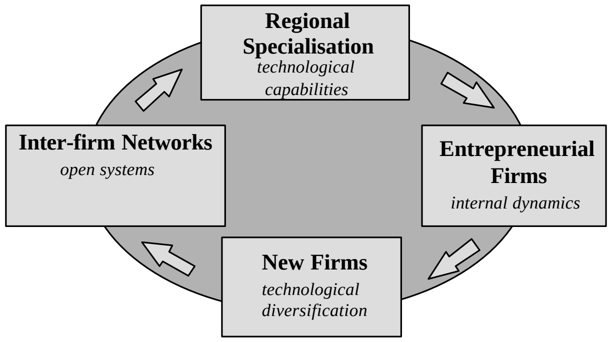
Growth of the entrepreneurial firm is characterised in terms of an internal, technology capability/market opportunity dynamic. The internal growth dynamic of entrepreneurial firms lies at the core of a set of regional growth dynamics or cluster dynamics. Figure 2 characterises the extension of the technology/market growth dynamic of the firm to the region by way of open-systems networking processes.

**FIGURE 2**

**Regional Growth Dynamics**

8 *Parallels can be drawn between the capabilities and innovation perspective and neoclassical growth theory. The concepts of production function and the factors of production labour, capital, and land are replaced by production system and business model, production capabilities, and skill formation. The concept of a Capability Triad has a certain similarity to total factor productivity, but the systems integration feature of the critical variables denies their divisibility. One strength of the capabilities and innovation perspective is that technology is integrated into the concept of growth and not treated as exogenous. Technology is also endogenous in the 'new growth theory' but it is not anchored in production capabilities; as a consequence, technology management lacks conceptual integrity.*

9 *At the level of the firm, this means that to move, for example, to multi-product flow (JIT or agile production), a company must simultaneously replace batch with flow production principles, supervisor with team-centred work organisation, and educate workers and managers in problem-solving practices and their new roles. At the level of the region, it means that, to jump to higher productivity and per capita income economic performance, change has to be co-ordinated at the level of business organisation, technology management, and educational system.*




Together they drive cluster dynamics. The figure identifies the processes required for clusters to add value to a region's resources. Each sphere and process will be examined. We start with the concept of the entrepreneurial firm.

### *Entrepreneurial Firms*

The business model of price-led competition was designed to compete on the basis of low cost production. Product design, new product development, and technical change are *exogenous* to production activities. The internal organisation of the price-led business model was constrained by the form of competition in the product market. Firms that sought to develop new products risked losing market share to lower cost producers of standard products. The dynamic between price-led competition in the market and internal organisation of the enterprise was self-reinforcing. Price-led competition and price-taking firms formed a single process. The resulting dynamic constrained both new product development and technology management.

The growth driver in the capabilities and innovation perspective is the entrepreneurial firm. As a business model, the entrepreneurial firm is driven by a *technology capability/market opportunity* dynamic, an endogenous process, built into the ongoing operations of the firm.[10] Firms pursue market niches by developing unique production capabilities, often of a technological form, but the process of developing such capabilities creates new market opportunities in the form of a redesigned product to meet customer needs better.[11] The interactive process is endless.[12]

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[10] *The term technology/market dynamic is an abbreviation 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 and forthcoming).*

[11] *It is, at the same time, an extension of Adam Smith's principle of increasing specialisation from skills and occupations to capabilities as mediated by business and industrial organisation. This theme is elaborated in Best (1999a).*

[12] *Individual firms may be entrepreneurial for a long or short period. From a regional policy perspective it is not important that individual firms survive but that the technology/market dynamic be ongoing as*

New 'market' opportunities feed back to motivate changes in productive capabilities, setting in motion a new technology and market dynamic. The commodity producer is ill equipped to meet the New Competition. Firms which lack unique capabilities also lack the capacity to anticipate emerging market opportunities and thereby differentiate their product in the market place. They are price-takers trapped by externally imposed market forces leaving the enterprise with little productivity-advancing and growth-driving force.

The entrepreneurial firm has taken various forms, but a common feature is the integration of design and manufacturing. The *kaisha* or Japanese variant of the entrepreneurial firm decentralises design and builds continuous change into the operating units.

The rapid gain in market share by Japanese enterprises in many industries in the 1970s and 1980s was achieved, in part, by designing a complementary *incremental innovation* capability into production. A product-led business strategy and the *kaisen* or continuous improvement work system established a Japanese variant of the entrepreneurial firm. The problem-solving, self-managed, team-centred work system gave the new business model a flexible production platform for integrating design and production. It set a new global standard in time-to-market for new product development. The associated model of innovation was production-pull rather than R&D-push. The new business model *systematically* integrated technology management into production.

In the 1980s and 1990s, American industry undertook a transition to another variant of the entrepreneurial firm. An indicator of the diffusion of the new product-led business model is the transition from the 'scientific management' work system to 'high-performance work systems' (HPWSs).[13] 'Scientific management', a work system designed for price-led competition, could not survive the new performance standards in cost, quality, or time-to-market for new product development. Team-centred rather than supervisor-centred work organisation delivered superior performance and higher productivity. HPWSs combine quality-improvement teams, problem-solving skills, and group incentive pay schemes.

This, the American variant of the entrepreneurial firm, has been one that more fully exploits the opportunities of information technologies. The result has been a deepened integration of manufacturing and design that enhances design experimentation and incorporates various R&D activities into production. In the entrepreneurial firm, information technology is not a separate department but integral to new capabilities in rapid product development, technology

*firms exit and enter. In this, the entrepreneurial firm functions like runners in a relay race, handing the baton on after having done their job in advancing the region's technological capabilities and redefining the market.*

13 *The proportion of employees in firms that 'made some use of self-managed teams increased from 28 percent in 1987 to 68 percent 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: 9). They continue, '[w]orkers 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 (e.g., engineers, accountants, maintenance and repair personnel), and, in some instances, with vendors or customers' (p. 7).*

management, and networking. Here, as in the Japanese variant, the entrepreneurial firm is characterised by high performance work systems.

Intel is an example. Intel is internally organised to combine recurrent phases of bottom-up experimentation and top-down direction (Grove, 1996). 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 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 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 the ability to manage organisational change; leaders must gain personal commitment to new directions, technologies, processes, and products. Without personal commitment from top to bottom, human energies will not be mobilised to drive the redirection of organisational resources. While experimentation demands turning everyone into a designer, direction demands that everyone enthusiastically accept the winning designs. This is no small organisational challenge. It involves aligning individual intentions and actions to common purposes. It stretches the concept of the entrepreneurial firm.

The fully-developed entrepreneurial firm can be distinguished in three domains. First, while the old business model pursued price-led competitive strategies and had no incentive to develop *high-performance work systems*, the entrepreneurial firm pursues product-led competitive strategies and depends upon high performance work systems. Second, the new business model *integrates design and manufacturing* which is required for compression of new product development cycle times. And, third, the entrepreneurial firm is part of an internal/external dynamic based on *open-systems networking*. This dynamic fosters the decentralisation and diffusion of design and thereby enhances regional innovation. Each of these characteristics, in turn, reinforces and replenishes entrepreneurial firms.[14]

### *Techno-diversification*

The link between the boxes at the right and bottom in Figure 2 represents a 'techno-diversification' dynamic between entrepreneurial firms and 'new firms' or new activities within companies specialising in the requisite capabilities. Whilst pursuing its goals, the entrepreneurial firm propagates new productive opportunities that can be either pursued internally or pushed outside the firm.

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

[14] *Information technology, alone, will not create the entrepreneurial firm. But digitisation is a great facilitator of the entrepreneurial firm, much as electrification was a great facilitator of mass production (see footnote 38 below and Best, 1997).*

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.

The originating firm can generate three types of new productive opportunities for other firms that can, in turn, foster secondary internal dynamics in follow-up firms. First, because of the inherent uncertainty about future technological pathways, the entrepreneurial firm must place its R&D and new product-development bets on specific opportunities and forsake the internal development of others. The choice to abandon certain opportunities may say less about the odds for future success than about sustaining the value of the firm's existing knowledge base. Second, the new opportunities may not offer the scale required by the existing organisation.[15] In both cases, productive opportunities that have been created but not pursued represent market opportunities in the market 'interstices'.[16] They are potential productive opportunities for new enterprises, spin-offs, or existing enterprises with capabilities in similar activities.

Third, if the entrepreneurial firm is part of a networked group of firms each specialising in a complementary capability, a technical change at one link in the chain will create new pressures and opportunities for specialists in each of the complementary capabilities. In this way, advances in design and technology are both diffused and interactive across production networks. In some cases, the effect may be one of induced technical change which, in turn, may set off a secondary internal dynamic and consequent pressure for change across the network.

New firms are often the path to techno-diversification. Moreover, new firms and spin-offs can trigger a process of industrial 'speciation' or the emergence of new industry sub-sectors. Classic examples are the transistor, the telephone, the laser, and the personal computer. The companies that sponsored the original research developed none of the key technological innovations even though they all became the basis for the emergence of a vast range of new enterprises better positioned to read and seize the opportunities. In most cases, the new companies were not saddled with already existing capabilities in competing technologies. Unlike the originating enterprises, they were not forced to make a decision between supporting core technologies and associated skills and new technologies and the new skills.

The process of techno-diversification can operate on a much smaller scale. In any case, new firm creation is often critical to the emergence of new industrial sectors and business models. For example, new firms pursuing new technologies with new business models drove the resurgence of Massachusetts' Route 128 following the demise of the minicomputer industry.

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15 *Gordon Moore, a co-founder of Intel, makes the point that a single firm cannot pursue multiple technological capabilities simultaneously: 'integrated circuits, MOS transistors, and the like proved too rich a vein for a company the size of Fairchild to mine, resulting in what came to be known as the 'Silicon Valley effect'. At least one new company coalesced around and tried to exploit each new invention or discovery that came out of the lab' (Moore, 1996: 167).*

16 *Interstice is Penrose's term for niche-market opportunities that have not yet been pursued.*

The new open-system business model fostered much greater technical diversity and industrial speciation.[17]

In these ways, the growth dynamic of entrepreneurial firms feeds into the larger industrial system. But the story does not stop here. A growth impact is not automatic: it depends on choices made within the originating firm, inter-firm organisation, and extra-firm infrastructure. Furthermore, the relations between firm and regional growth dynamics are not one way. They too are interactive.

***Networking***

The box at the left of Figure 2 represents inter-firm networking. Three types of inter-firm relations can be distinguished: market, closed-system or Japanese *keiretsu*, and open-system networking. Inter-firm relations are structurally linked to intra-firm organisation: First, Big Business and arms-length, market-driven supplier relations, and, second the *kaisha* (Japanese) 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-systems networking, commonly referred to as ‘horizontal integration’, multi-enterprise integration, cooperation, networking, or affiliated groups of specialist enterprises. Open-systems networking is the inter-firm counterpart to increasing specialisation of the entrepreneurial firm. It has proved 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 nodes in the value networks.
Open-systems networks convert the inescapable dilemma of the individual entrepreneurial firm into a growth opportunity for a region’s collective enterprises. 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, both existing and new, to respond to new market and technological opportunities.[18]

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

17 *These themes are developed in Best (forthcoming).*

18 *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).*

'third Italy' (Best, 1990: chs 7-8). 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 dynamics of entrepreneurial firms simultaneously enhance *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 its opportunity. The firm's dilemma is a *cluster constraint* in a region populated by enterprises that are vertically integrated.[19] But the firm's technology choice dilemma is a *cluster opportunity* in a region with 'open-systems' networks.

The goal of the entrepreneurial firm is to develop the organisational capability to differentiate its product in the market place and to 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.[20] 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 one design possibility. The open-systems organisational

19 *Externally-integrated enterprises are defined as productive units coordinated within 'closed-system' inter-regional networks or value chains directed by global enterprises.*

20 *Horizontal integration, the term used by Andrew Grove of Intel to describe open-systems networking, can be considered an inter-firm consequence of Intel's production concept of integrated manufacturing (Grove, 1996; Best, 1998).*

model is fostered by open systems in the form of standardised interfaces and shared design rules at the technological level.[21]

The Internet is a great facilitator of the 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. Virtually seamless integration across businesses enhances the simultaneous increase in specialisation and integration that Adam Smith identifies 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 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 new specialist firms can readily plug into pre-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 that distinguishes itself from other firms and thereby gives it market power.

The entrepreneurial firm start-up system is particularly strong in the Silicon Valley and Route 128/495 high tech regions in the United States 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. Most attention has been focused on financial markets as the enablers of the emergence and development of the entrepreneurial firm. Venture capital and 'initial public offering' (IPO) capabilities are certainly contributors to the high new firm creation rates in both Silicon Valley and Route 128/495. Important as financial commitment is, however, 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

[21] *The idea of systems integration suggests a common design principle that enables the integration of independently designed components. The term 'open system' suggests that the system design rules are openly published. A closed system, in contrast, suggests the challenge of integration is achieved by an overarching design principle which leaves no space for independently designed components. The IBM 360 computer, for example, was a closed system before an anti-trust ruling forced the publication of the system design principle and thereby began a process that led to an open system. The embedded and private operating system of Massachusetts mini-computer companies is another example.*

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 but 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 metamorphoses 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 trajectory can create obstacles to technological transition. Hence networks enable new entrants to focus on a technological capability and partner for the complementary capabilities. Regions with open-systems 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 2 signifies the extent of capability specialisation and diversity within a regional population of industrial enterprises. Specialisation has regional and inter-regional dimensions. Greater specialisation internally is a measure of technological diversity within a region. Greater specialisation externally, or across regions, is a measure of uniqueness of regional capability and thereby regional competitive advantage.

Regional specialisation results from cumulative capability development and the unique combinations and patterns of intra- and inter-firm dynamics that underlie enterprise and regional specialisation. Successful industrial districts are the outcome of historical processes of capability development, often of a technological character. For example, the success of New England in jet engine production has a technological genealogy that goes back to water turbine innovations in the 1850s to power the region's textile mills.

To contribute to economic growth, technologies must be embedded in production systems. The processes whereby technological capabilities are embedded in a company's and a region's production systems are 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.

A region's technological capabilities are like a seabed or industrial ecology, in which entrepreneurial firms are spawned, grow, and die. At the same time, however, entrepreneurial firms, driven by a technology capability and market opportunity dynamic (see footnote 10), are forever advancing their own capabilities.[22] In the process, the region's technological capability

[22] *As a business model, the entrepreneurial firm is driven by a technology/market dynamic, an endogenous process that advances a firm's technology capability and refines product definition. Firms pursue market niches by developing unique production capabilities, often of a technological form, but*

seabed is revitalised by the ongoing 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.

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 extends a region's unique technological capabilities. The regional process of technology capability advance will probably involve a succession of firms, with new firms building on advances made by previous innovators. Regional specialisation, in the form of industrial districts or clusters, is the outcome of the technology/market dynamic played out at the level of the collective entrepreneurial firm. For example, distinctive regional technological capabilities lie behind the competitive advantage of the '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'.

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.[23]

Recently, high tech regions have developed similar capabilities for rapid design changes 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 continuously combining and recombining across a population of 6000 high tech firms, making it an unparalleled information and communications technology industrial district.[24]

Models of innovation are associated with different business models. The *kaisha* variant of the entrepreneurial firm decentralises design and continuous change into the operating units. As outlined above, the rapid gain in Japanese market share in many industries in the 1970s and

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*the process of developing such capabilities creates new market opportunities in the form of a redesigned product to better meet customer needs, which sets the dynamic in motion again.*

23 *The regional model of innovation offers a decentralised, self-organising explanation not only of the success of high tech regions but of industrial districts in general as an alternative to the linear, science-push model of innovation. In the latter, 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.*

24 *Intel is not the only driver of new products. Approximately 1 in 5 of the Silicon Valley (and Route 128 in Massachusetts) publicly traded companies were 'gazelles' in 1997, which means they have grown at least 20% in each of the last 4 years (the number for the US is 1 in 35). See Massachusetts Technology Collaborative (1998).*

1980s was achieved, in part, by designing a complementary incremental innovation capability into production. It fostered a technology-pull model of innovation. An American variant, and perhaps advance, is the leadership and design dynamic which combines top-down and bottom-up actions captured by Andrew Grove's leadership/design dynamic (see Grove, 1996).

The regional model of innovation derives from the open-system, regional growth dynamics (the diffusion and development of a range of growth dynamics ensuing from the entrepreneurial firm). 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 speciation. Thus the regional growth dynamics are an infrastructure for new industry incubation and formation.

The concept 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.[25] 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 region takes on more the semblance of a collective entrepreneur. The virtual collective entrepreneurial firm is a self-organising agent for change composed of networked groups of mutually adjusting enterprises.[26] The collective entrepreneurial firm is a composite of networking firms that collectively administer the regional growth dynamic processes of Figure 2.

While the high tech districts are unique in terms of specific technologies and research intensity, they exhibit regional innovation characteristics in an exaggerated form that are common to the virtuous circle of regional growth. Three examples follow.

First, the high-tech, open-systems industrial district is, as well, a collective experimental laboratory. Networked groups of firms are, in effect, engaged in continuous 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. However successful the industrial district as a mode of economic coordination has been in international competition, heretofore, it has been considered appropriate only to 'light' industry such as the design-led, fashion industries of the 'third Italy' and the machine tool and metal working regions of Baden-Württemberg in Germany.

[25] *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.*

[26] *See Best, 1990: 207-8.*

Second, an open-system district expands 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. In this way, a district counters the barriers to introducing new ideas in firms that already have well-developed capabilities around competing technologies.

Third, an open-system district fosters the decentralisation and diffusion of design capabilities. Design modularisation in the personal computer industry is an example. IBM got the process underway with the modularisation of the 360 computer that created an open system. This was greatly enhanced when Microsoft and Intel developed the design modules for the operating system and the microprocessor.[27] The resulting standards have created enormous market opportunities for specific applications software. But, in addition, the concept of design modularisation combines common interface design rules with decentralisation of component design. This diffusion of design capability increases collective innovation capacity. It can also strengthen the district model of industrial organisation, and even encourage conversion from a closed to an open system.[28]

**Production Capabilities**

In this section, the production capabilities required to achieve internationally competitive performance standards are examined. Production capabilities are an expression of an underlying but unifying principle of production and organisation.

Five production system (PS) models are distinguished in Table 1.[29] The major theme is that the success of a business strategy in achieving any of the performance standards in column 3 depends upon developing a production system around the principle in column 4. Column 2 offers an historical example of a pioneer in establishing the associated production system that enabled the enterprise to achieve the performance breakthrough of column 3. Columns 4 to 8 fill in distinctive features of the respective production system, in terms of the links between underlying production principle, target application of the principle, production capability, technology management and business model.

One of three principles of production underlies each production system: inter-changeability, flow, and systems integration. The principle of flow is distinguished in terms of its application: it can be applied, first, to single products, as in the case of Ford; second, to multiple products on the same assembly line, as in the case of the Toyota production system; or, third, to new

27 *See Katz (1996: 15). Katz also describes network economies and increasing returns.*

28 *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).*

29 *The table is described more fully in Best (1998). The above is a summary statement from ongoing research on principles of production and organisation. The method used for discovering the principles is to examine historical shifts in industrial leadership.*

product development, as in the case of Canon. Each of these applications, shown in column 5, is expressed in different production capabilities, shown in column 6. Column 7 identifies the vehicle for technology management associated with each production system, and column 8 indicates the form of co-ordination across production units associated with distinct business models.

Each production system represents a discontinuity in performance standards associated with a reorganisation of production according to a more advanced principle of production or application to a higher challenge. The advance in production principles is expressed in production capabilities. The original application of each principle was the basis for a new competitive advantage and industrial leadership based on superior business models and performance standards.[30]

## TABLE 1

## Production System Models

| 1 Production Systems | 2 Exemplar | 3 Performance Breakthrough | 4 Production Principle | 5 Application | 6 Production Capability Advance | 7 Technology Management Vehicle | 8 Industrial Organisation |
|---|---|---|---|---|---|---|---|
| **PS 1** | Armory | Standard-isation | Interchange-ability | Product Parts | Product Engineering | Specialist Machine | Open System |
| **PS 2** | Ford | Cost (economies of time) | Flow | Single Product | Throughput Efficiency (synchronisation) | Exogenous (R&D lab pipeline) | Vertical Integration |
| **PS 3** | Toyota | Flexibility and Quality (inventory turnover) | Flow | Multiple Products | Incremental Innovation (cellular manufacture) | Process Innovation (shopfloor incremental) | Closed Network |
| **PS 4** | Canon | New Product Cycle Time | Flow | New Products, Technology Adoption | New Product Development | Applied R&D (design + manufacture) | Closed Network |
| **PS 5** | Intel | Endogenous Technology Innovation | Systems Integration | Technology Integration (multiple technologies) | Design Modularisation | Technology Teams (R&D + manufacture) | Open Networks |

30 *The diffusion processes include the cluster growth dynamics of techno-diversification and integration. But the success stories also create role models for other enterprises and competitive pressures for organisational change.*

Table 1 illustrates a simple business policy idea: competitive strategy and production system are bound together. Any effort by business managers to advance performance outcomes that do not put in place the requisite production capabilities will not be able to compete against firms that have done so. Competing on the basis of rapid new product development, as we shall show, without having a production system in which manufacturing and design are integrated, will only produce frustration. Competitors that have integrated design and manufacturing will be equipped to introduce new technologies smoothly in support of new product concepts on a regular basis.

These themes are explored in terms of advances in production capabilities. We start with throughput efficiency, an expression of the principle of flow.[31]

***Throughput Efficiency***

The principle of flow underlies myriad terms used today to describe the revolution in manufacturing led by the Japanese, such as Just In Time (JIT), agile manufacturing, 'lean production', 're-engineering', advanced manufacturing, time-based competition, process integration, and 'synchronised production'. Earlier, Henry Ford's engineering team applied it to achieve an order of magnitude increase in throughput efficiency and an unprecedented jump in productivity and wages. It required the development of process engineering and the redesign of production around the concept of equalising cycle times. This organisational change was enabled by, and in turn drove, the integration of electric motors and machines.

Application of the principle of flow for Ford meant equalising cycle times and the development of process engineering. Process engineering involves the redesign of plant layout, machining activities, and operator tasks according to the logic of the product (the sequence of activities required to make each requisite part). The unit of time became *cycle time* as the metronome governing every activity; it replaced *labour time*, the unit of pre-flow production systems. Co-ordination was achieved by the self-organisation of thousands of production activities each producing according to the logic of cycle time, not by the scheduling instructions of the planning department. The cycle time required to achieve throughput efficiency replaced labour time, the time unit of 'scientific management', and revolutionised work organisation.[32]

The breakthrough in production performance demanded that Ford's engineers focus their attention on *technology management* and measures of throughput efficiency, not on *labour management* and measures of labour time and labour productivity. An example is the

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31 *For a discussion of the principle of interchangeability, see Best (1990 and 1998).*

32 *Achieving Ford's order of magnitude increase in productivity not only required the co-development of technology, plant and work organisation. It also depended upon the co-development of a labour force with the skills to achieve and maintain economies of time in material flow; conventional wisdom to the contrary, the requisite skills are not those elaborated in 'scientific management' manuals. Such manuals were not informed by Ford's challenge: revamping production and work to achieve high throughput efficiency. Managers, engineers, and workers trained and skilled in Taylor's terms defined production efficiency in terms of designing pay incentives to maximise labour effort; the result was local optimisation, a violation of the concept of flow.*

concurrent development of machines powered by attached electric motors and Ford's production line. Both were the result of simultaneously redesigning the production system and the elements in it to capture the full advantage of technical change in the electric power delivery system.

The limits of Ford can be seen in the same terms. Instead of the institutionalisation of innovation, both incremental and radical, into the organisation, Ford saw it as a one-off activity focused at the time of development of new plants.[33] To make the transition to the permanent integration of technology management and production would have required a greater revolution in work organisation and labour skills. But Ford set the stage by revealing the power of the principle of flow. It took others to extend it, first to multiple product systems, then to new product development, and finally to technology integration. Ironically, the practice only became a principle with the development of the Toyota Production System that, in fact, was a major extension of the principle of flow from single to multiple products. This extension, however, requires a deep change in production organisation.

### *Incremental Innovation*

The principle of flow applied to multiple products is the secret to achieving high throughput efficiency in 'lean production' or the Toyota production system. It is an extension of the principle of flow but depended upon prior or simultaneous changes in work organisation associated with cellular manufacturing methods including the associated practices of JIT, quick changeover machines, *kanban* (visual co-ordination of production activities), self-directed work teams, and *kaizen* (Japanese for continuous improvement methods). Application of the principle of multi-product flow established comprehensive performance standards involving cost, quality and time that cannot be matched with other high volume production systems.

The application of multi-product flow at Toyota meant the corresponding development of a plant layout and the range of skills to carry out cellular manufacturing. The new production system required multi-skilled workers capable of operating and setting up a range of machines, departments organised by process and not similarity of machine or activity, and work organised into teams inclusive of the various skills and range of activities required to carry out the process from beginning to end. Flexible production means workers educated in blueprint reading, in the range of problem-solving tools that constitute quality management including statistical process control, and in the communication skills required to work in teams.

The conducting of experiments and the discovery of new knowledge was no longer the preserve of engineers but spread to work teams. The business challenge became that of building the discovery process into every ongoing activity of the organisation. In practice, this meant the establishment of *kaizen*, or continuous improvement work organisation, a foundation for incremental and collective innovation and for the pursuit of product-led competition. Extending cycle time competition from production to 'time to market' of new product designs meant integrating design into the manufacturing process. Workers become part of the technology adaptation process.

[33] *Ford plants were not static, but subject to serial revamping in search of bottlenecks by engineers.*

The plan-do-check-act methodology, team-centred work organisation, and inclusion principle of 'total quality management' are a set of skills and practices that constitute the organisational counterpart to multi-product flow; skills, organisation, and material conversion technique are three aspects of the same, flexible production system. The comprehensive performance standards of cheaper, better, and faster can be achieved only if the triad of production principle, business model and skill formation is 'in sync'.

The skill level undergoes another change with the integration of the new product development process and manufacturing to compete on the basis of short product cycle times. The rapid introduction of new products means the incorporation of technical change as an ongoing activity in the production system. This means combining incremental innovation and the systematic introduction of new technologies: new technologies are pulled into the production system to achieve new product development goals, rather than being pushed in from outside as a consequence of science-driven innovations. The organisational capability to manage 'technology transitions' means that systems integration-related skills are required of shop-floor workers.

The principle of flow applied to new product development involves a major advance in technology management capabilities. It is the secret behind the Canon production system.

***New Product Development***

The starting point for distinguishing the new from the old business systems is the dominant form of competition. The defining feature of the old competition when it emerged and the reason it successfully put all competitors on notice, was that it drove down the costs and prices of production. The defining feature of the new competition of today is rapid new product development created by the marriage of productivity and innovation, and the redefinition of both. Whereas productivity and innovation were a tradeoff in the old competition, they have become a dynamic in the new.

Both the old competition, when it was the new, and the new competition of today generated a change in order of magnitude in business performance. Henry Ford, as the paradigm case of the old competition in its heyday, drove down the price of the Model T to a fraction of the competition of the time. Today, the leading competitors successfully introduce new products in a fraction of the time of the competitors that are mired in the old principles of production and organisation. The result is a new manufacturing and innovation dynamic.

The term dynamic is used to capture the transition from a trade-off between two goals to a mutually reinforcing interaction: improved performance in achieving one goal enhances performance in the second, and *vice versa*. In recent years, the quality movement exposed the presumed trade-off between quality and cost that was taken for granted in the era of Big Business. Leaders in quality turned the trade-off into a dynamic: higher quality products generated, in the long run, lower cost products. Transcending the quality-cost trade-off is not costless in the short run: without a substantial investment to make the transition from the 'scientific management' to the plan-do-check-act (PDCA) paradigm of work organisation, quality improvement will remain a futile exercise in exhortation.[34]

Today, however, high quality and low cost does not offer a formula for sustained success. Firms must be able to produce faster and develop new products quicker. Producing in less time involves an organisational change that complements PDCA, namely, application of the principle of flow, in this case multi-product flow. The organisational vehicle for applying the principle of multi-product flow is cellular manufacturing or group technology. Like the principle of flow, first applied to discrete product manufacturing processes by Henry Ford, the principle of multi-product flow demands process integration: production must be organised to connect sequentially the series of activities required to complete the process. A fully developed application of flow is the repudiation of batch production methods and the achievement of one-piece flow with multiple products.

The principle of flow and the related concept of process embody the idea of systems integration; without the principle of flow, production is broken down into a series of local optima which generate system inefficiency. The ideal of multiple-product, one-piece flow is not limited to the production process. Fully developed new competition is about the reorganisation of business enterprises into a series of core processes each organised according to the principle of (one-piece) multi-product flow. In most cases this means extending the idea of process from manufacturing or material production to processes that involve business activities. For example, the order fulfilment process involves the flow of information (previously the flow of paper) as distinct from material. The economics of time, however, demand that both processes be integrated.

The core process most important to this discussion is the new product development process, one that has been most refined in the electronics sectors where product 'life' cycles have been systematically reduced. Anyone with a personal computer is cognisant of the ever-shorter product life span of electronic components and products.
While the pace of change is greatest in the electronics industry, the trend is pervasive. The New Competition is product-led. Product-led competition has opened up a new competitive dynamic between innovation and productivity. Driving down manufacturing cycle times is important because it means more rapid response, more reliable delivery dates, higher inventory turns, and better quality. Driving down the design/manufacturing cycle time is equally important: it determines the pace of technological change that a company can sustain. The design/manufacturing cycle is the time it takes to convert a new product design into a scaled up plant capable of producing at competitive costs.

The extended design/manufacturing cycle includes all of the following activities:

**concept development**
product architecture

[34] *See Ishikawa (1985) for an elaboration of PDCA. While the technical aspects of quality control were an American import, their integration within the inclusionary practices of the post-war Japanese firm created a vehicle for converting the factory into a learning organisation. Goal-setting and problem-solving became constitutive of work on the shop-floor as never before.*

conceptual design
target market

**product planning**
model building
small-scale testing
investment/financial

**product/process engineering**
detailed design of product and tools/equipment
building/testing prototypes
setting standards

**pilot project/scale-up**
volume production prove out
factory start-up
volume increases to commercial targets

**production**
maintaining standards
continuous improvement.

Several abbreviated variants of the design/manufacturing cycle can be distinguished. A job shop, for example, may always be producing new products but will short-circuit the scaling up activity. A batch producer may respond to new orders with new product specifications that can be run through the existing production system with minimum alterations.
For any single design/manufacturing cycle, product and process ideas are locked into place for the duration of the cycle. To change any part requires new tooling, altering supplier specifications, new testing, changing work tasks, etc. Each new cycle, however, is an opportunity for the introduction of new technological ideas (Gomory, 1992).[35]

The shorter the design/manufacturing cycle, the greater the opportunity and capability to introduce technological innovations into production. A company capable of reducing the design/manufacturing cycle to half that of a competitor can introduce technological innovations at twice the rate. Being first to market with a new technology is important, but having the shortest design/manufacturing cycle time is more important in that technological refinements can be introduced more rapidly.[36]

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[35] *Ralph Gomory makes this point in distinguishing 'the cyclic process' from a 'ladder' type of innovation. 'Ladder' refers to the step-by-step process in an innovation that descends from science downward 'step by step' into practice. 'The cyclic process' refers to 'repeated, continuous, incremental improvement' built into a series of dynamic design/manufacturing cycles. I am indebted to Gomory for his formulation if not his metaphors.*

[36] *The engineering change orders and other changes required to implement rapid new product development are not conceivable under the Taylorised, specialised organisation of work associated with Big Business. That organisation of work was not set up to deal with quality, productivity, or*

Over time, the technological gap widens between companies with rapid and slow design/manufacturing cycle times. The technology dynamic is reinforced by higher profit margins which create funding for increased research, design and engineering (RD&E) which, in turn, enhances the investment in and introduction of new technologies.[37]

The design/manufacturing cycle or new product development process cannot be understood as a one way flow of either material or data, but it can be reorganised into a sequence of activities several of which involve inherently group activities and feedback channels.

If the first dynamic of the New Competition is the integration of design/manufacturing and manufacturing cycle times, the second is the integration of both with technology diffusion. Since a firm can only introduce new technologies with the introduction of new products or model changes, technological change must be synchronised with the beginning of a design/manufacturing cycle. In between, the firm can practice continuous improvement but not innovation.

Historical studies of the technology diffusion cycle point to a 25-50 year cycle. But these studies have been conducted on innovations embedded in the old organisational dynamics. What is new is the development and management of a technological diffusion infrastructure that begins with the industrial process and thus reinforces the second innovation path. But the power of attraction of new technologies is what drives the speed-up in technology diffusion. The new manufacturing and design/manufacturing dynamics were a prerequisite to driving down the technology diffusion cycle and gave the impetus to establishing non-linear technology diffusion infrastructures.

Industrial policy, to be successful, must be informed by these new competitive dynamics. Too narrow a focus on either one-on-one technical help or an exclusive focus on helping firms acquire state-of-the-art technology does little to help firms improve their manufacturing processes nor does it diffuse technology in ever widening circles. Product-led competition requires a corresponding production-focused industrial policy, one that focuses on building the capacity of firms and sectors to respond to global manufacturing challenges.

To summarise this section, product-led competition has engendered new organisational capabilities that involve the redefinition and integration of three processes:

1. manufacturing: the cell is the building block of the whole edifice; without cellular manufacturing the rest of the business system cannot drive product-led competition.

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*innovation. The PDCA model of work organisation is a prerequisite for rapid new product development, as is the development of a quality system. Shorter cycle times demand that the job be done right the first time.*

37 *The concept of the design/manufacturing cycle is critical to drawing a distinction between two paths to innovation and to understanding the barriers to rapid new product development in the hierarchical enterprise. A rigid, specialised work organisation is not the only barrier to new product development. Equally important is the separation of engineering from production; the decline of design engineering with the rise of engineering as applied science; and the taken-for-granted notion that industrial innovation is a by-product of scientific breakthroughs.*

2. the design/manufacturing cycle: companies need to compete on the basis of rapid new product development or they will fall behind in technology adoption.

3. technology diffusion: this is *pulled* by the first two processes as distinct from being *pushed* by autonomous R&D activities.

We turn next to design modularisation. This is a powerful new production capability and an expression of the principle of systems integration. It brings the concept of technology management into considerations of competitiveness as never before.

***Design Modularisation***

The systems integration challenge is not unique to the new model of technology management. Henry Ford and his chief engineer, Charles Sorensen, would have understood the challenge, and rewards, of systems integration.[38] Applying the principle of systems integration entails redesigning the product from inside-out and outside-in to enhance flow. Popularly known as concurrent engineering, new products (inside) are designed simultaneously with production (outside).[39]

But concurrent engineering alone does not capture the full growth and innovative potential of the principle. Systems integration is a dynamic concept with respect to *component design rules*; it implies openness to innovation or technological change. In contrast, a common response to the challenge of systems integration is to freeze technological change. *Kaizen*, or continuous improvement management, pursues experimentation and technological improvement but *holds basic technology design rules constant*.

The organisational challenge at Intel is to manage manufacturing processes along a technology trajectory in which productivity is advancing according to Moore's Law at 50% every 18 months. This involves integrating and reintegrating technologies themselves being independently redefined. Systems integration is the response. It is about building the organisational capability to incorporate rapid technological change in components into complex products. Design modularisation is an enabling methodology that integrates two sets of design rules: those at the level of individual technologies or sub-systems and those that integrate sub-systems into a single system. The process of integrating sub-systems is not an

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[38] *Ford was acutely aware of the opportunities offered by redesigning a whole system to fit the requirements of a seemingly independent technological innovation. Ford redesigned the production system to take advantage of new electric power technologies, particularly distributed or fractionated power designed into each machine (Best, 1997). Technology management for both Henry Ford and Intel involved a double redesign challenge: redesign of technologies to fit production and redesign of production to fit the new technologies and technology combinations. Ford's engineers revamped machines to fit the cycle-time standard by adjusting, for example, tooling, material, and machine speeds. Ford and Intel do not simply add new technologies to the existing system: the idea is to redesign the system to take full advantage of the new technology to make a leap in production performance.*

[39] *For details, see Best (1998).*

additive one, particularly when sub-systems have independent design and development dynamics. Interactions amongst subsystems have dynamic feedback effects.

An advantage of design modularisation is the potential to mobilise resources from outside the company for component design and to meet the challenge of rapid technological change. Unlike Ford's business model, an Intel depends upon, and reinforces, a network of affiliated companies constituted by multiple design nodes. Intel not only partners a vast array of specialist producers and research institutions, it also draws upon an extended industrial high tech region with an extraordinary capacity to conduct experiments, carry out innovations, and conduct research.

Versions of design modularity existed in earlier industrial orders but the emergence of new information and communication technologies has fostered new and more comprehensive applications. Systems integration flourishes with entirely new resonance in the age of product-led competition. It creates new opportunities for business strategies based on the integration of design and production. Following *interchangeability* and *flow*, systems integration is both a fundamental principle of production and a business-organising concept.

The new competitive advantage derives from the application and diffusion of the principle of systems integration. Systems integration involves the modularisation and decentralisation of design in conjunction with shared inter-face design rules and, simultaneously, the replacement of the business model of vertical integration with one of horizontal integration across networked groups of companies. Systems integration often entails the fusion of two or more technologies each of which is anchored in different scientific disciplines and associated 'language communities', and which operate according to different design protocols; hence the organisational imperative of teamwork across scientific backgrounds. The most evident case of systems integration is the integration of hardware and software that, with advances in information technology, has created the opportunity to continuously rethink product concept across most industries.

Information technology has played a double role: enabler of (i) systems integration and (ii) open systems in both technology design and industrial organisation. In fact, the microprocessor is to the knowledge-driven economy what the machine tool industry was to the diffusion of the principle of interchangeability and unit-drive electricity was to the diffusion of the principle of flow, which ushered in the age of mass production (Best, 1998). In each case, a new principle of production was associated with the development of a new business model capable of achieving a breakthrough in performance standards that redefined the basis of industrial leadership. Like the emergence of the machine tool industry and fractionated electric power, information technology has fostered an entirely new approach to product architecture and production organisation, and a business model which in turn has redefined industry boundaries.

The open-systems, networking model of industrial organisation both fosters and is fostered by systems integration at the enterprise level. As the case of Intel illustrated, rapid new product development entailed the integration of manufacturing and R&D, which, in turn, fostered design modularisation at the inter-firm level. Design modularisation requires networking, a dynamic mutual adjustment process in which the capabilities of each firm undergo change. The process does not stop here. The response to the new challenge leads to potential tensions between each company's core capabilities and its emerging capabilities. The established and the emerging capabilities may or may not be compatible. New firms are created out of this tension.

The resurgence of both Silicon Valley and Route 128 has been driven by a mutually reinforcing combination of information technology innovations and open-systems industrial districts. The refinement of computer aided design has enabled a shortening of the new product development cycle and a substantiation of systems integration. This has brought to centre stage in companies the continuous refinement and redefinition of product concept, often the starting point of innovation. The pursuit of innovation means both networking with companies specialising in complementary technologies and internal systems integration.

Innovation networks are enhanced in an open-systems district as opposed to a vertically integrated enterprise. This is because barriers from bureaucratic inertia are lowered and companies can integrate, disintegrate, and re-integrate with other companies as technologies change. Thus the cluster fosters a dynamic involving networking, systems integration, and diversity. Information technology, by fostering new capabilities in systems integration has worked hand in glove in reinventing the industrial district as a model of industrial organisation.

This process of combining, reconstituting, and spinning off from both technologies and companies is a perpetual process in open-system networks. It offers an explanation of high value-added associated with integration and packaging capabilities.[40] The trick is to know when to pursue each as the objects of both bundling and unbundling are perpetually being redefined in the process. The combination of systems integration and vertical disintegration operate side by side, and they are speeded up in an open-system that fosters networking, techno-diversification, and industry speciation.

To summarise, the evolution of the entrepreneurial firm has enjoyed a step change advance with, first, the extension of the principle of flow to new product development and, second, the development of the principle of systems integration. These advances, in turn, have facilitated a new model of technological innovation that has given new meaning to the technology/market dynamic. It is an error to think of the advances in regional productivity in regions such as Silicon Valley and Route 128/495 simply as technological advances. They represent a New Competition that involves an advance in technology management capabilities.

### *Technology Management*

Technology management has two domains: as it relates to R&D processes, and as it relates to production. The meaning of technology management has shifted from the former to the latter with the advance of production capabilities and the evolution of business models. The functionally departmentalised organisational structure of Big Business established one-way links between R&D and production. The organisation was not designed for reverse feedback effects from production to product design or from product concept to technology development.

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[40] *The concept of integrate and package is used to explain Hong Kong's regional advantage in Enright et al. (1997).*

Technology management was limited to the confines of R&D laboratories. New technologies would be introduced into production at irregular intervals but with considerable resistance and severe 'teething' troubles during which quality and output suffered. Changes were highly disruptive to production performance and were to be avoided. The business model was well suited for a world of long production runs and predictable product life cycles. Technology management was an obstacle to be avoided.

Some firms, in R&D intensive sectors, pursued the technology/market dynamic of the entrepreneurial firm. They, too, however, separated technology management from production. The lack of technology management capability meant that new technologies would often mean investment in new dedicated facilities. Here, too, the product life cycle metaphor mirrored real world conditions. Many took the metaphor to be like a natural law instead of an organisational challenge.

The evolution of the entrepreneurial firm is about the integration of technology management with production and the redefinition of both. Technology management is about the capability to develop and introduce new technologies, machines, materials, techniques, and methods into production to improve production performance.[41] It includes the capability of enterprises to create, develop, adopt, adapt, combine, re-engineer, upgrade and otherwise advance technologies for the purpose of increasing productivity.

**Skill Formation Processes**

The links between technological change, industrial innovation, and regional economic growth go beyond the introduction of new technologies.[42] The technology development and diffusion process depends upon the growth and proliferation of business enterprises with the requisite technology management capabilities and a labour force with the requisite skills.

The development and diffusion of a new technology depends upon a scaling-up of engineering and related skills to sustain the inter-firm or regional growth dynamics (see Figure 2). While some of the skill development will be internal to the firm, much of the education embodied in science and engineering graduates is not.

The growth process in knowledge-intensive industries is limited by the supply of engineering and scientific personnel required to staff rapidly growing firms. Any individual firm can attract from the existing pool by offering superior pay and conditions, but the success of the region

41 *The productivity of the 'factors of production' of labour, capital and natural resources depends upon the capabilities of the organisations within which they are embedded. Efforts to explain productivity and competitive advantage in terms of measures of inputs of 'factors of production' ignore the mediating role of capabilities. The failure to account for capabilities explains the large unexplained 'residuals' in growth accounting exercises.*

42 *Bob Forrant makes the point that while CNC machine tools were developed at MIT they were refined, simplified, and diffused in Japan. The Japanese model of work organisation made it easy to integrate the new technology and exploit its potential for flexible production. The American model of work, based on 'scientific management', used the new technology for purposes of high volume production and did not exploit its true potential.*

depends upon enlarging the pool. William Foster of Stratus Corporation uses the metaphor of a food chain to capture the hiring process:

> The most critical thing in starting a computer company is being in an area where there are a lot of big computer companies so you can draw experienced people away from them. And the big computer companies need to locate in an area where there are a lot of schools so that as they lose people to the start-ups, they can replace them with people fresh out of school. I see that as the key to the whole food chain for the Route 128 area. If the big companies weren't here, we wouldn't be here, and if the schools weren't here, the big companies wouldn't be here. (Rosegrant and Lampe, 1992, pp. 158-9)

The rapid growth in technical skill levels that has accompanied the high growth rates in the East Asian 'miracles' is shown in Table 2. Singapore, South Korea, and Taiwan all followed

**TABLE 2**

**Growth in Engineering and Science Graduates, 1975-1995**

First university degrees awarded in natural science (NS), engineering (E), and mathematics (M) and computer sciences (CS) in 1975 and 1995.

| | 1975 NS&E | 1975 M&CS | 1995 NS&E | 1995 M&CS |
|---|---|---|---|---|
| Ireland | 706 | NA | 5456 | NA |
| Singapore | 702 | NA | 2965 | NA |
| South Korea | 10266 | Nil | 47277 | 12351 |
| Taiwan | 6700 | 1200 | 15170 | 2818 |

Source: National Science Board, *Science and Engineering Indicators—1998*, Appendix Table 2-2 , Washington DC: US Government Printing Office and, for the RoI, *Twenty-Second Report, 1995*, National Council for Educational Awards.

Japan in investing heavily in engineering, natural sciences, mathematics and computer science education to make technology-driven growth happen.[43]

The output of engineers alone in Singapore increased *7 times* between 1975 and 1995.[44] The

43 *The RoI, the fastest growing region of Europe in the 1990s, is the same story. Government led the growth with large investments in regional technology colleges. In all cases, without synchronised investments in education, growth would have been choked. Instead, a virtuous cycle emerged that funded the advances in education by rapidly growing national income.*

44 *Singapore has pursued a strategy of attracting multi-national companies (MNCs) and, at the same time, developed indigenous production and technology management capabilities. Singapore, like Taiwan and*

number of graduate scientists/engineers in South Korea increased by nearly *5 times* over the same period. The RoI,[45] the fastest growing region of Europe in the 1990s, tells the same story.[46] Its output of scientists and engineers increased over *7 times* in the same two decades. These numbers all testify to the industry and education dynamic captured in Figure 3. In all cases, without the investment in skill formation, growth would have been choked. Instead, a virtuous cycle emerged that funded the advances in education by rapidly growing national income.

*South Korea, has major education programmes to upgrade their skill base continuously. Unlike Singapore, Malaysia has yet to turn heavy reliance on technology imports into indigenous production capabilities. The critical factor is the development of a local skill base that can serve as a medium for absorbing and diffusing technology and technology management capabilities in local firms (Best, 1999b).*

45 *Government led the growth with large investments in regional technology colleges.*

46 *See Figure 4 for a similar explosion in output of engineers accompanying the 'Massachusetts Miracle'.*

The figure titled Regional Growth Dynamics and Skill Formation (Figure 3) indicates linkages between regional growth and engineering education institutions. Matching supply of and demand for technical skills is a long-term, mutual adjustment process requiring institutional co-ordination. Regional growth, represented by the growth dynamics on the left-hand side of the figure, will be choked if the requisite numbers and types of graduate engineers are not produced by the education system, represented by the demand for and supply of technical graduates on the right-hand side of the figure. Three conditions must be met for success. The first involves characterisation of the demand for specific technological skills; the second, investment in technical education; and the third, skill formation in the workplace.

### *Technology Change and the Engineering Curriculum*

The challenge of engineering education is exacerbated by technological change. The link between entrepreneurial firms and engineering graduates is mediated by engineering curricula. During normal times, updating the engineering curriculum does not present a challenge. But at times of technology paradigm or domain shift, such as from the age of mechanical to electrical technologies, the issue of the curriculum becomes paramount. Firms seeking to advance their technological capabilities in opto-electronics, for example, seek graduates educated in photonics as well as electronics. This means that the challenge for educational institutions is not simply to increase the number of graduates but to increase graduates educated in a curriculum that includes emerging technological methodologies.

The mutual adjustment process between technology-driven enterprises and university curricula is critical to an understanding of both Silicon Valley and Route 128. Silicon Valley and Stanford University, in the words of Leslie and Kargon,

> 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 characterized 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. (1996, 470)

But the development of appropriate engineering methodologies within education institutions is not sufficient for regional industrial growth. The supply of engineering graduates must be 'in sync' both in skill and quantity with the demand from technology-driven firms. The supply response depends both on the appropriate curriculum and the 'ramp up' capacity of the region's education institutions.

### *Investment in Technical Education*

The remarkable feature of the 'Massachusetts Miracle' years (1978 to 1986/7) was the responsiveness of the education system to the skill needs of the rapidly growing firms. The result was a step increase in both engineering graduates and the technical skill base of the region. Entrepreneurial firms, educational institutions, and government funding went into partnership to provide the skill base required to fuel the growth and development of America's first high tech regional concentration.

**FIGURE 3**

**Regional Growth Dynamics and Skill Formation**

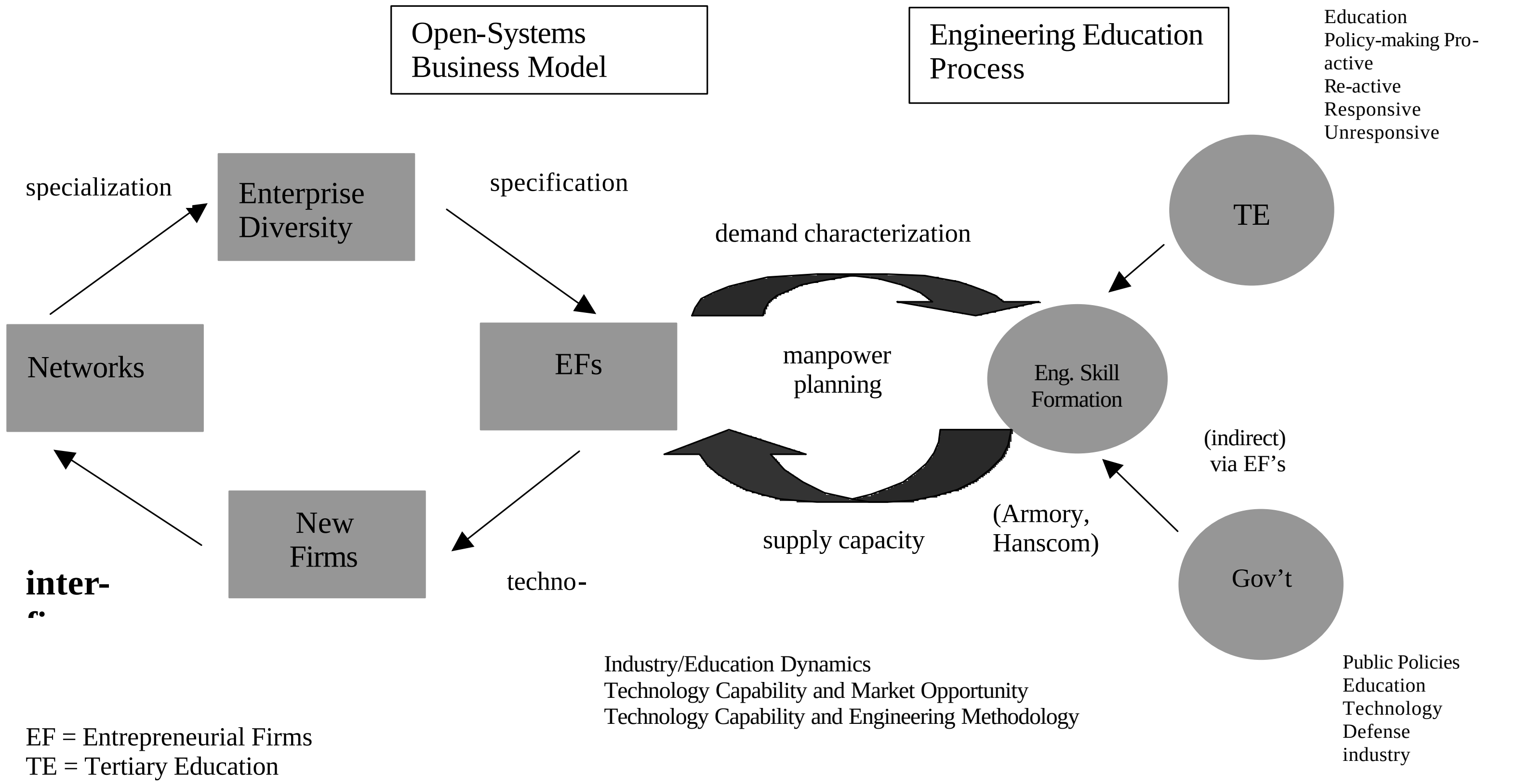
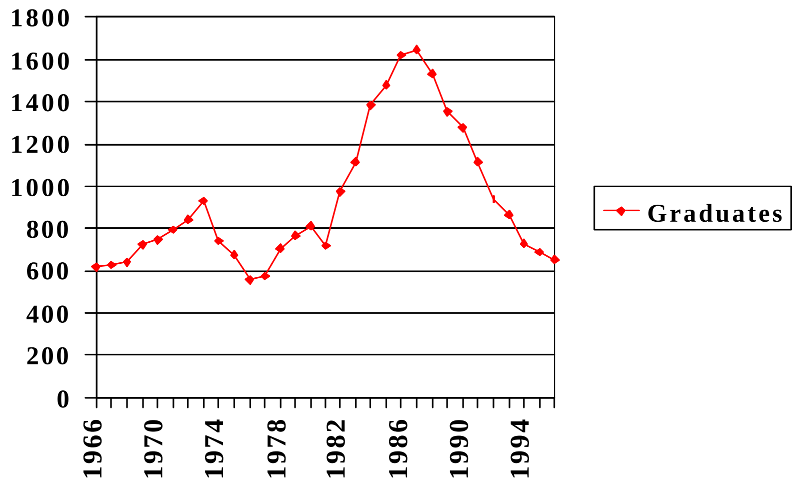


Figure 4 reveals the extraordinary supply response to the technology capabilities being developed during the Massachusetts Miracle. The number of BA degrees in electrical engineering conferred by Massachusetts' universities and colleges increased from a low of 561 in 1976 to 1648 in 1988. The expansion in a region's 'production' of engineers is a costly process (though also potentially highly productive). An expansion in graduates by 1000 a year requires an increase of 4000 students in four-year electrical engineering degree programmes which, in turn, requires an expansion in university teaching positions of roughly 270 (given a 15:1 student to staff ratio) in electrical engineering plus a corresponding investment in facilities.[47]

**FIGURE 4**

**Bachelor Degrees in Electrical Engineering in Massachusetts, 1966-1996**




[47] *A ballpark estimate for expanding the electrical engineering graduates by 1000 during this period is $50 million annually. Assuming an annual salary of $60,000 in the 1980s this translates to over $16 million in annual salary costs. A rule of thumb is that salaries in engineering and applied science must be matched by a 1:1 increase in costs for teaching and staff assistants, disposable materials, and bricks and mortar. This doubles the staff salary cost to over $30 million annually to fund the expansion of 1000 engineering graduates. To expand the number of college engineering students by 4000 (1000 graduates) would require an increase in the number of high school students in sciences and mathematics of roughly 8000. This translates to 270 new high school teachers of sciences and mathematics. At a student to staff ratio of 30 to 1 and a 1980s average annual salary of $50,000, the total annual salary costs would have added to $13.5 million. If we assume a facilities and non-teaching staff cost of half, then the annual cost for high school education to expand the number of engineering graduates by 1000 per year was $20 million in the 1980s.*

*Source: Michael Best, 'Technology Integration and the Resurgence of Route 128' Umass Lowell working paper, 1999*

Investment in skill formation is costly. To get a high return in the investment, it is important to match the demand for skills from technology advancing firms with the supply from education institutions. The tripling in electrical engineering graduates during the 1976 to 1986 period, as noted above, was coordinated by three institutions: technology-driven firms, education, and government. Only the government has both the funds and legitimacy to make educational restructuring and investments on the scale involved. Nevertheless, the state government was not the leader but a third partner in the implementation of an informal manpower development plan. The rapidly growing, technology-driven firms were the active partners.

***The Invisible College***

Much attention has been given, rightly, to the links between formal education and growth. Less attention has been paid to the informal, regional processes by which knowledge is created, adapted, modified, and diffused in the workplace.

The concept of the invisible college underscores the shared creation and diffusion of knowledge within technical or occupational communities that cut across companies. Here, knowledge is created and diffused in ongoing production activities as workers address challenges and devise new methods. The informal, skill formation dimensions associated with production are rarely examined and subjected to improvement. Nevertheless, they are important to understanding economic progress.

In fact, technology diffusion and skill-formation go hand-in-hand in industrial transitions. The technology diffusion process depends upon the skill formation level and capability built into the work organisation of a region's enterprises. As a region's enterprises move up the production capabilities spectrum, these communities progressively advance in skills. The diffusion of technical knowledge takes place in hundreds of ways as individuals in different firms tackle common problems, share new methods, advance their skills, and move from firm to firm.

Every region that has made the transition to PS 3 (Table 1) has simultaneously incorporated a variant of the *kaizen* or continuous improvement model of work organisation across a critical mass of firms. The pace is enhanced by a shared supplier base of small and medium-sized enterprises (SMEs) that can achieve world-class performance standards in cost, quality, and time.

Continuous improvement in work organisation is a counterpart to process integration in material flow or just-in-time production. Multi-skilling, particularly across functions, is a by-product of making the transition from 'scientific management' models of work organisation and functionally departmentalised models of factory organisation to high performance work system (HPWS) and production systems organised according to the principle of flow.

The revolutionary idea was to design quality into the system rather than 'inspect' it in. It required the development and diffusion of problem-solving skills throughout the organisation.

Firms that make the transition from supervisor-centred to self-directed work organisation enjoy a leap in direct labour productivity as many non-direct labour functions such as quality inspection, supervision, scheduling, and coordinating are increasingly internalised into work teams. But the effects of the revolution did not stop here. The new idea laid the foundation not only for the quality revolution but also for rapid cycle-time competition. The transition meant the extension of short cycle times in production to short cycle times in new product development (see PS 4 in Table 1). Short cycle-time production capability entails the integration of design and production to pull new generation technologies quickly into production.

An array of terms is used to capture a set of organisational innovations that have emerged to institutionalise the learning process within production.[48] *Kaizen*, Total Quality Management (TQM), PDCA, self-directed work teams, and HPWS are all methodologies to convert production into a learning system receptive to sustained improvements including technological advance. They share a view of work organisation that runs counter to the set of principles embodied in 'scientific management'.[49] Breaking the dichotomy between thinking and doing in the workplace has profound implications for our views about skill formation, education and theories of growth.[50]

**Conclusion: Growth and the Capability Triad**

In this chapter we have examined the economics of industrial growth from the capabilities and innovation perspective. First, we examined the business model and, in particular, the internal growth dynamics of the entrepreneurial firm. We located the entrepreneurial firm within a set of regional growth or cluster dynamics. Second, we explored production capabilities, one of which is technology management. Lastly, we focused on skill formation by articulating the links between cluster growth dynamics, technological advance and diffusion, production capabilities and manpower development planning.

The capabilities and innovation perspective outlines dynamic growth processes that can explain high rates of growth for a decade or more. Technology is critical to rapid growth, but

48 *The work organisation revolution involves the extension of the organisational principle of pinpointing power and responsibility throughout the organisation. The principle of pinpointing power and responsibility is the idea that those who have the responsibility for achieving certain goals must also have the authority to get the job done. Responsibility without power leads to alienation; power without responsibility fosters despotism. This principle is the starting point for the practice of inclusion that is universal to workforce involvement programmes.*

49 *Louis Brandeis, not Frederick W. Taylor, coined the term 'scientific management' and Taylor's system was probably never applied precisely according to Taylor's principles. Nevertheless, the term has considerable meaning and does capture the approach to the management of production that distinguished the old competition.*

50 *The exemplar of 'scientific management' is that of Schmidt, the pig iron loader made famous in the writings of Taylor. By studying the loading of pig iron with the aid of a time watch, Taylor and his associates were able to locate the single best method that would maximise labour productivity. A pay incentive system could then be devised to motivate the worker to act according to the standard.*

the challenge is to develop the technology management capabilities of both firms and regions so that technological advance is built into the production system.

Technology management capabilities involve the capacity of a region's enterprises to develop, diffuse, adopt, adapt, and combine technologies. Advancing a region's technology management capabilities involves synchronising the three elements of the region's Capability Triad - business model, production capabilities, and skill formation - into an interactive dynamic by which each advances together.

A technology management transition growth scenario can involve making a transition in Figure 5 from an industrial structure heavily weighted in the south and east poles in the direction of the west and north poles.[51] This requires moving up the production capabilities spectrum shown in Table 3. The associated business models and industrial organisation are

**TABLE 3**

**The Production Capabilities Spectrum**

1. **Pre-flow, pre-interchangeability**: craft production, by itself, offers no basis for flow. Each drawer is custom fit. The task is to develop product engineering skills. Jamaica and Honduras.
2. **Interchangeability** (*PS 1*): product engineering without process engineering, hence low inventory turns and working capital productivity. Cyprus and Slovenia in the 1980s.
3. **Single product flow** (*PS 2*): plants with economies of speed for a single product or range of products with dedicated lines. Workers are not multi-skilled; they tend 1 or several homogeneous machines. (Training does not include continuous improvement, rapid changeover, or blueprint reading skills.) Multi-national electronics production in Indonesia.
4. **Single product flow with continuous improvement** (*PS 3*): involves problem-solving *self-directed* work teams. Common training programmes involve Plan-Do-Check-Act, the 7 problem-solving tools, 5Ss or TQM at shop floor level.
5. **Single product flow with process innovation** (*PS 3*): personnel include maintenance and process control technicians with skills to identify, fix and redesign machinery and production lines. Bottleneck analysis determines priorities. This may involve reconfiguring product design parameters at main office as required by design for manufacturing (DFM). Singapore in the mid-1980s, Malaysia multi-national companies (MNCs) in early 1990s.
6. **Multi-product flow** (*PS 3*): the Toyota system. *Kanban*, JIT, and single-minute exchange of dies (SMED) are introduced in large plants. High throughput and flexibility are combined. Cellular production with self-directed work teams.
7. **Multi-product flow and product development** (*PS 4*): Japan and Taiwan both excel at concurrent engineering and design for manufacturability. Skills include reverse engineering, prototype development, and pilot runs.
8. **New product design and technology fusion** (*PS 4*): Japan's Toshiba and Canon are leaders in linking development to operations at the plant level and linking research in generic technologies to product development. Core technologies are developed, often via fusion in generic technology laboratories. Technology management involves world-wide sourcing of the existing technology base in pursuit of novel applications.
9. **Systems integration and disruptive innovation** (*PS 5*): 3 M, HP and Motorola use cross-disciplinary teams to identify new technology drivers for product development. Disruptive or breakthrough innovations are pursued but within an organisational context of process integration. The integration of hardware and software drives product concept development.
10. **Open systems and design modularisation** (*PS 5*): focus and network strategies are supported by standard inter-face rules and diffusion of design capability. Fosters technology deepening R&D and techno-diversification.

[51] *The technology intensity of Northern Ireland industry can be found in NIEC (1993: 19, Table 3.2).*

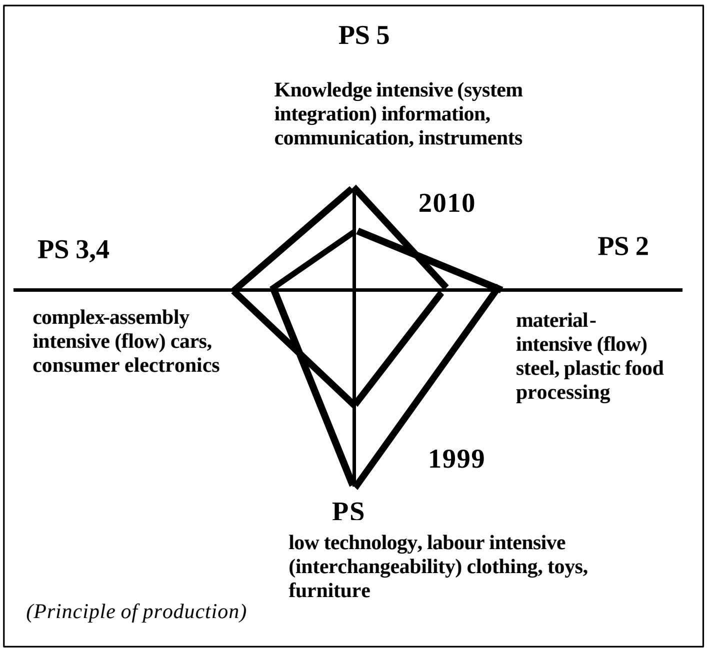
shown in Table 1. Diversification into complex production activities means developing and applying the principle of flow to multiple product production and new product development. Becoming a fast cycle-time competitor involves successful deployment of a range of manufacturing capabilities such as total quality management, quick changeover methods, and *kaizen* (continuous improvement/incremental innovation work organisation). In terms of industrial organisation it means replacing market driven inter-firm coordination with networks, closed and open.

The transition to knowledge intensive sectors, the north pole in Figure 5, means the application of the principle of systems integration (see Figure 6 below for an example from Northern Ireland), open-systems networks, and a range of regional innovation capabilities (abbreviated as the 5Ds in footnote 28**)**.

Making a transition to higher technology management capabilities does not, however, require moving resources into sectors associated with the west and north poles of Figure 5. Instead, it involves applying and, in some cases adapting, the organisational principle of increasing specialisation and advanced production principles to 'low-tech' sectors associated with the

**FIGURE 5**

**Evolution of Industrial Structure**



south pole. It requires triggering regional growth dynamics, which, in effect, pull a range of inputs from the west and north poles into products associated with the south pole.[52]

Such districts depend upon the full range of dynamics associated with the regional growth dynamics to sustain growth: entrepreneurial firms driven by internal growth dynamics; techno-diversification and open-system networking; and increasing specialisation. With these three dynamics under way, the regional innovation processes assist in sustaining growth even though wage levels are high and the final product is 'low-tech'. Regional growth dynamics are distinguished by consistency with Adam Smith's fundamental principle of increasing specialisation both internally and externally. Internally, micro-diversity is endless; the continuous reconstitution of the firms via open-system networking and the associated external/internal dynamic means that the region, as a whole, is shifting its sectoral centre of gravity.

The highly successful 'third Italy' 'furniture industry', for example, has evolved into an 'interior design and furnishing industry' in which the material wood plays a significant but minuscule role in product characterisation; information technology, such as computer-aided design, becomes an input for low-tech applications. In this way, the microprocessor is a modern day functional equivalent to the machine tool in the mechanical age as a vehicle for increasing specialisation and returns.

Figure 7**,** titled Plastics Industrial Food Chain, captures the extreme specialisation and diversity of a low-tech sector in Massachusetts, a high-income region. The second column lists 9 plastics processing technologies used by firms in column 3 to develop specialist capabilities and supply unique inputs into a range of end use markets. Knowledge-intensive inputs come from a range of extra-firm agencies listed in the lower right-hand corner. Nevertheless, success depends upon innovation. Figure 8 shows a range of companies and research streams associated with the Biodegradable Polymer Research Centre. This Centre is itself an example of systems integration R&D internally; the principle researchers combine the disciplines of chemistry, biology, chemical engineering, and physics. Externally, the supporting companies use the Centre to conduct research into the technological fundamentals underlying the production processes required to convert biodegradable materials into 'plastics' products.

Successful technology management demands must be accompanied by manpower planning at governmental level.[53] It even suggests that regional or national technology management is the supply side, or productivity-enhancing counterpart to the statecraft of demand management.[54]

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[52] *Articulating a technology management strategy is central to economic policy-making for a developmental state. The range of industrial policy instruments applied by Japan, Taiwan and Korea to foster sectoral transitions offer a range of possibilities (Johnson 1982; Best 1990: chs. 5-6). However, distinctive technology management strategies in each of the high growth East Asian countries can be identified. In fact, the idea of national technology management is to the theory of the developmental state what demand management was to Keynesian economics or money supply management is to monetarism.*

Firms, of course, do not compete alone in the international marketplace; they compete as networked groups of enterprises. Here the term network has connotations of regional capabilities and regional competitive advantage. The goal of a fast growing economy depends upon the development of regional competitive advantage; an industrial policy which articulates a strategy for achieving regional competitive advantage can provide leadership to align the visions of hundreds of independent firms around a shared growth trajectory. But, like the leadership of a large company, to be credible and inspire commitment the vision must connect with an objective assessment of strengths and weaknesses, opportunities and threats. The capabilities perspective provides criteria for assessing competitiveness and shaping a regional

strategy.

The adjective *regional* in regional growth dynamics and regional technology management, for example, implies that, while entrepreneurial firms are the drivers of growth, they are embedded in multi-group communities. Firms, individually and collectively, pursue market opportunities but, inevitably, their focus is short run. Skill formation is long run.

The noun *dynamics* in regional growth dynamics implies that growth is about incessant change. Change means winners and losers not only amongst firms but all members of the community. Fostering an environment in which growth is sustainable means investing in skill formation for two reasons: to foster bottom-up entrepreneurial activities and to reduce the barriers to change with institutions that spread the benefits and costs of upheaval. Investment in skill formation thus plays a direct and indirect role in growth.

Growth depends upon skills that match the advances in production capabilities and upon reducing the barriers to change from those who bear the cost of technological change. Individuals in communities that invest in skill formation are in a better position to anticipate, respond to, and benefit from change. Policies that reduce the barriers to change are simultaneously enablers of change. For both reasons, skill formation is a critical component in growth-oriented industrial policy.[55]

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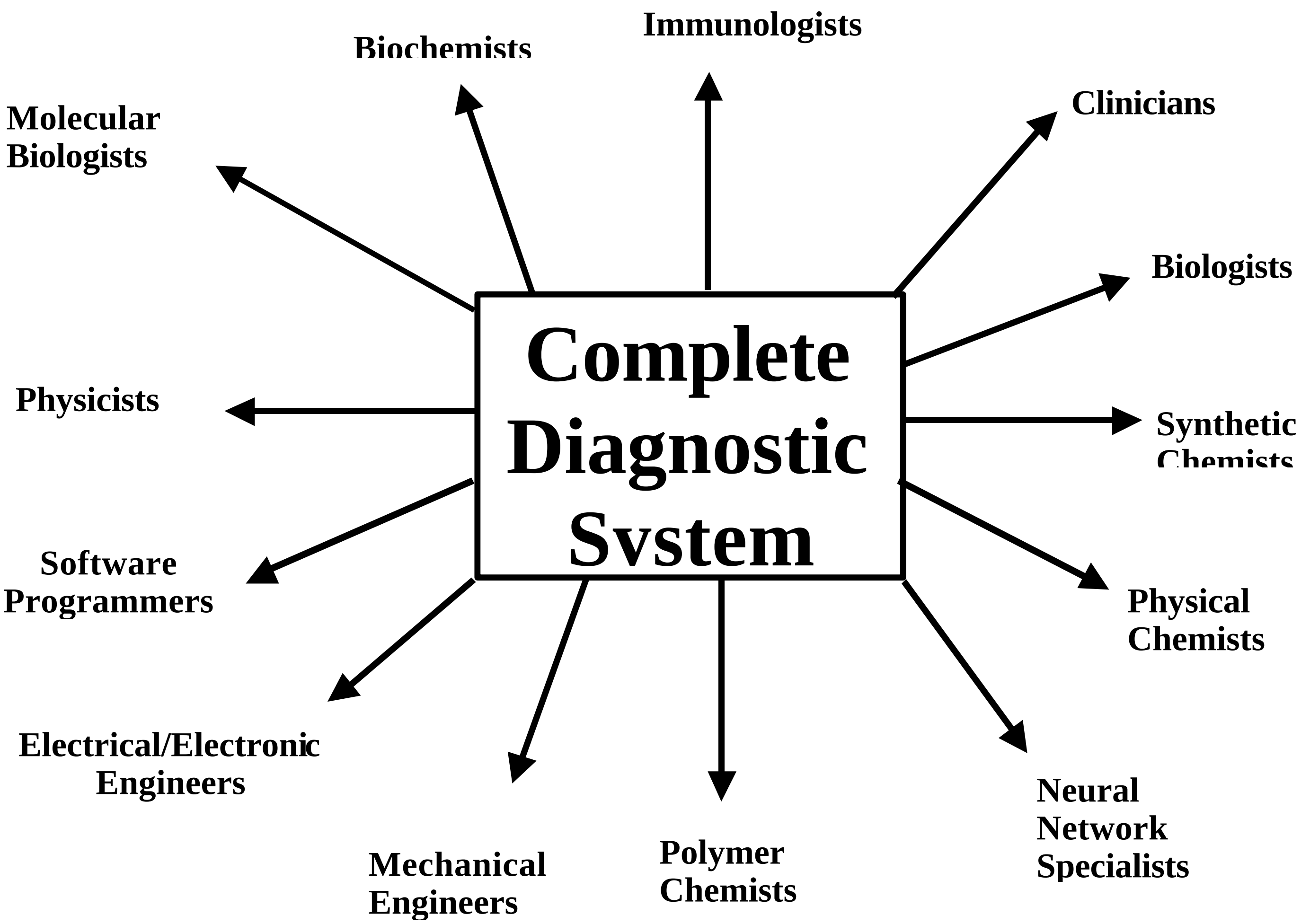
53 *For an Irish example, see FAS (1998).*

54 *The Capability Triad is a force for social inertia like John Maynard Keynes' liquidity trap. The liquidity trap meant that no amount of increase in money supply would stimulate demand and growth without a simultaneous improvement in expectations of future growth ('marginal efficiency of investment'). In the case of the Capability Triad, no amount of investment in R&D without advances in technology management capabilities, an appropriate business model and a facilitating inter-firm or industrial organisation will stimulate growth.*

55 *But skill formation, as a process, is also a metaphor for participatory methodologies in both enterprise and governmental policy-making. Growth is not a consequence of a linear sequence of vision, strategy, objectives, and action plans either in the firm or the community. It is more like the inter-relationships of a complex system in which changes in individual components precipitate adaptive changes throughout the whole system. In this, industrial policy-making must be organised to account for precipitators throughout the community just as the business model that embraces high-performance work systems is better fit to prosper in an era of product-led competition. For an application of systems theory to regional industrial development policy-making, see McGarvey (1999).*

**FIGURE 6**

**A Multi-Disciplinary R&D Group**




*Source: Randox*

## FIGURE 7

## PLASTICS INDUSTRIAL FOOD CHAIN

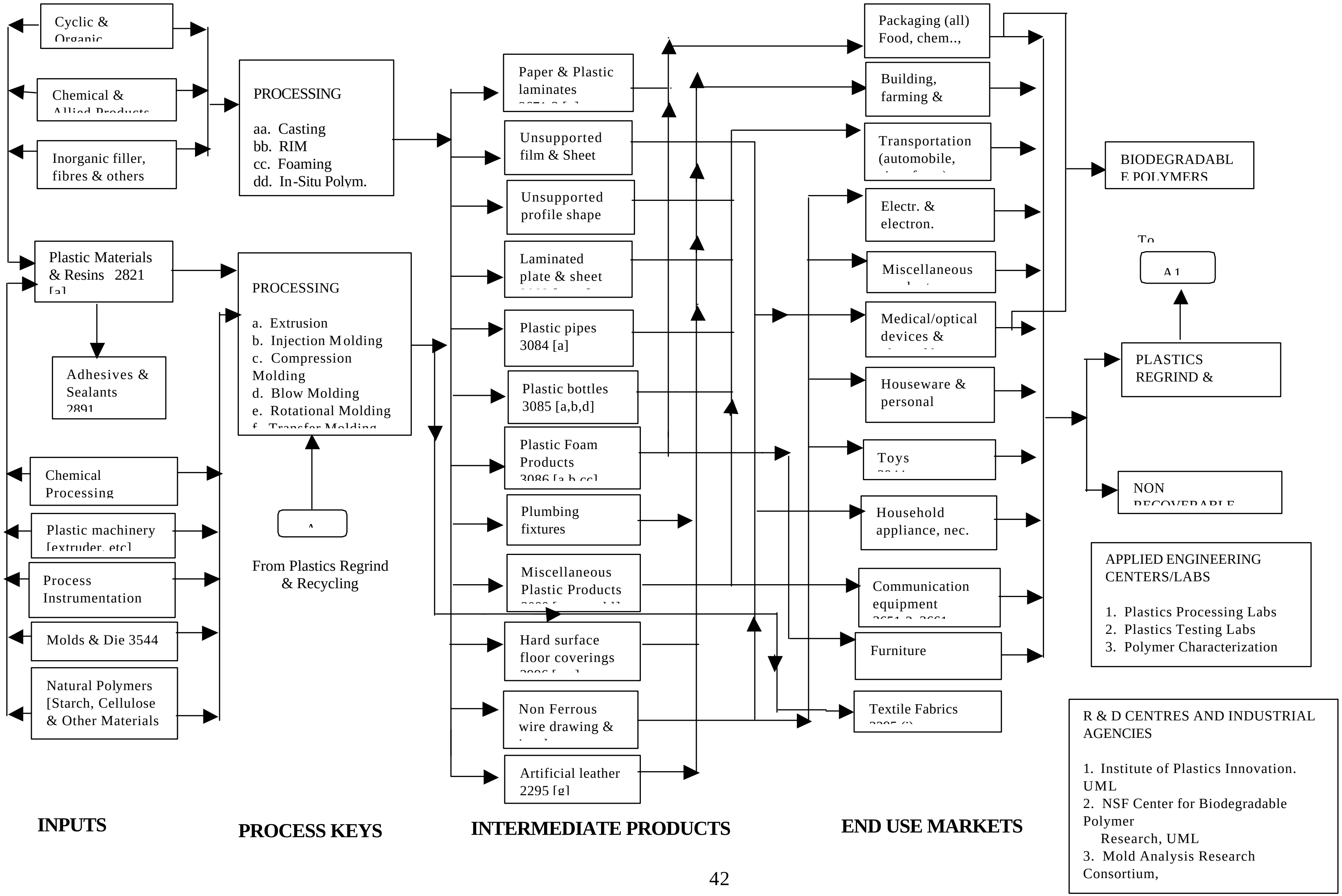
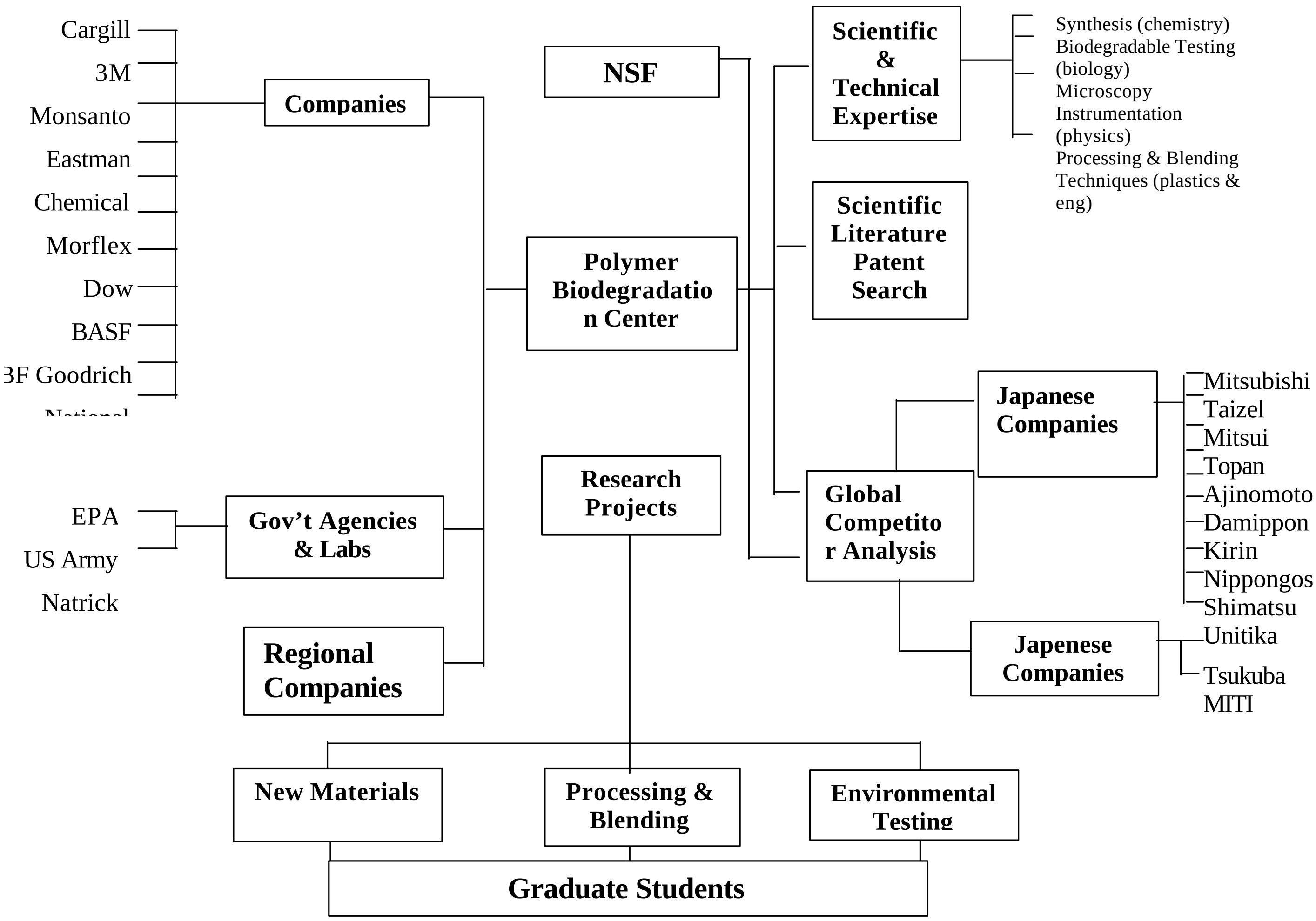


**FIGURE 8**

**Biodegradable Polymer Research Centre**




*A National Science Foundation Industry / University Cooperative Research Centre since 1993

# 3. APPLICATION TO NORTHERN IRELAND

The capabilities and innovation perspective focuses attention on three inter-related elements of the growth process: the business model, production capabilities and skill formation. In this chapter each is examined in the context of Northern Ireland.

The goal was to identify the fundamental obstacles to, and opportunities for, rapid growth. The methodology was to visit firms, government agencies, and educational institutions to interview key decision-makers and to benchmark organisational and production capabilities of the pacesetting firms and related growth-promoting agencies in a region. A benchmark analysis of the region's business model, production capabilities, and skill-formation processes uncovers the barriers to and opportunities for growth.[56] Appendix 1 lists the firms, agencies and institutions visited and the interviews conducted in Northern Ireland for this Report. The list was drawn up in consultation with the Industrial Development Board. The presumption was that most could be learned from entrepreneurial firms independent of industrial sector. Thus the sample of firms represents a cross section of industrial activities, including agricultural processing. However, the company visits were biased in favour of firms widely viewed to be success stories. We start with the business model.

### Business Model

The business model that prevails in Northern Ireland cannot be characterised as entrepreneurial. One indicator is innovation. Innovation is low by international comparison, particularly for countries with similar levels of advanced engineering and science skills. A recent Confederation of British Industry (CBI) survey of innovation expenditures found Northern Ireland to have the lowest reported levels in the United Kingdom. Northern Ireland manufacturers reported spending 2.5% of turnover on innovation compared to 12.2% for Wales (the highest region) and 6.8% for all cases (CBI 1998a: Exhibit 37). Unfortunately, the results of the CBI survey 'paint a disappointing picture of innovation in the UK' (CBI, 1998b: 4) which suggests that by global benchmarks, Northern Ireland suffers a sizeable innovation gap.

A second indicator is productivity. Here, too, Northern Ireland is low by comparison with the UK which, in turn, suffers a gap of 20-40% with leading European economies and the United States (DTI, 1998: Chart 3.11). In a matched plant comparison conducted in the late 1980s, Hitchens *et al. (1991)* found that productivity levels in Northern Ireland plants were roughly half that of their West German counterparts. There is little evidence of a reduction in the productivity gap over the 1990s by either academic studies or industry reports. The Northern Ireland Growth Challenge (1995) states:

> the failure by firms to innovate with new products and move on to higher value-added activities has led to limited/no up-grading of their sources of advantage. The result has been a relatively low-wage, lower value-added private sector economy, which faces the continuous threat of job losses through competition with the lower-cost emerging economies. (p. 9)

56 *The conceptual tools of the capabilities and innovation perspective, such as the production capabilities spectrum, penetrate the surface appearances of a production facility to expose the sources of productivity and competitiveness like an X-ray penetrates the surface to illuminate the condition of the skeleton.*

Fortunately, however, entrepreneurial firms can be found in Northern Ireland. They are beacons of light showing the way to a high growth future.

***Entrepreneurial Firms***

The starting point for considering growth dynamics in Northern Ireland is the entrepreneurial firm. Productivity growth is about increasing the rate and number of technology capability and market opportunity cycles that define entrepreneurial firms.

What are the criteria for defining an entrepreneurial firm?

- driven by a technology/market dynamic
- growing at a rapid rate (10+% per year)
- unique capability
- collectively entrepreneurial: balances top-down and bottom-up initiatives
- high performance work systems.

The technology/market dynamic is a shorthand way of expressing the production capability/market opportunity dynamic described in Chapter 2. The idea is that as firms pursue new technological possibilities they build capabilities (such as research teams) which, with each success, become excess capacity looking for new outlets; at the same time, innovations redefine the market and create new market opportunities where these firms have an initial advantage. The successful completion of a single cycle precipitates a new one.

While an audit of entrepreneurial firms in Northern Ireland does not exist, examples do.[57] Contrary to statements made in vision documents, Northern Ireland does not have an industrial history of entrepreneurial firms driven by internal dynamic processes.[58] But some are emerging. A short survey follows.

***<u>Boxmore</u>***

Boxmore is an entrepreneurial firm.[59] Its 25% annual growth rate over a decade and a half is supported by a productive capability/productive opportunity dynamic that is driven by alliances with the world's most successful pharmaceutical companies. These companies find

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[57] *The number of firms in Northern Ireland that could be classified as fast cycle time competitors (PS 4 in Table 1) is limited. No obvious locally owned candidates could be found. Some MNCs may fit the bill.*

[58] *Northern Ireland does have an illustrious industrial history beginning with linen and followed by shipbuilding and machine making (see O'Grada, 1994; Bardon and Burnett, 1996). Firms like Harland and Wolff were entrepreneurial in the sense of developing unique production capabilities, but it was an entrepreneurialism that was not endogenised into the production system and converted into an ongoing process. See also Checkland (1981) for the deleterious effects that concentration on limited technologies can have on a region.*

[59] *Boxmore employed about 1400 people and had a stock market valuation of £120 million in mid 1999.*

the customers, Boxmore supplies the packaging services. To realise the productive opportunity, Boxmore has developed rapid productive capability responses which often involve innovation of two types, seeking new technological combinations in materials, printing and packaging, and 'dip-down' innovation involving partnerships with Northern Ireland university research centres. When Harold Ennis, CEO, purchased Boxmore in 1983, it made fibre boxes, a mature product, for agricultural processors. To meet productive opportunities, Boxmore combined an ever-greater mix of technologies including printing; PET plastics to make bottles; fluorine gas to make inert, impact- resistant barriers to contain products that previously needed glass containers. At the same time, they were continuously upgrading the packaging materials to meet the needs of the world's market leaders in health care products. High volume needs were met by supplying only customers that wanted multi-site support around the world. They have diversified their customer base into the agri-chemicals divisions of the same pharmaceutical parent companies, and into beverages (including Guinness and Coca-Cola).

The strategy is to build network alliances with market leaders to supply packaging needs with innovative products. These market leaders provide incentives and ideas for product and service innovations in packaging. Recently, Boxmore bought the in-house packaging operations for Glaxo. Over the years, Boxmore has bought a range of small, family owned companies in Northern Ireland to implement new technology combinations. Boxmore invests at twice the rate of its competitors.

Early on, Boxmore invested in Information Technology (IT) to improve customer feedback, management information systems (MIS), plant and process performance, and computer aided design (CAD), and for benchmarking purposes including tracking patent developments. Modernisation and innovation has brought Boxmore into ongoing partnerships with both Queen's University Belfast (QUB) and the University of Ulster (UU) in using software for packaging and bottle design, and innovations in polymers and barrier technology.[60] These relationships enable Boxmore to pursue a pro-active innovation strategy rather than respond to the innovations of competitors. Success depends upon many factors, including good engineering and production people and managers with the ability to work with the world's best run health technology companies. Boxmore supplies a limited number of customers in Northern Ireland who benefit from the diffusion of best practices from Boxmore's sophisticated global customers.

Boxmore's success has meant that it enjoys 80-90% market share in the health technology packaging 'cluster' for Northern Ireland. Of the many lessons to be learned from Boxmore, one is that Northern Ireland is not large enough to support an entirely regional growth dynamic. Entrepreneurial firms are likely to be highly networked for complementary capabilities with firms in other regions.

***Randox***

[60] *Graphics design for advanced materials, for example, involves three-dimensional imprinting enabled by software advances. For this reason, Boxmore has to hire IT people. As part of health technology companies, Boxmore must keep abreast of developments in environmental technologies including recyclable and bio-degradeable plastics.*

Randox is a locally owned, knowledge-intensive entrepreneurial firm. The only UK manufacturer of clinical chemistry diagnostic reagents, Randox is also one of the world's fastest growing diagnostic companies exporting to 120 countries. The company employs over 80 research staff and is unique in its systems integration capabilities. Figure 6 shows the range of scientific and engineering disciples that this small company requires to meet international R&D standards. Randox demonstrates the meaning of technology integration teams.

Research is focused on developing new diagnostic products and new technologies. For example, Randox has invested £7 million in the development of a ' revolutionary diagnostic testing system which utilises biochip array technology enabling very high laboratory workloads to be carried out on one instrument' (IRTU, n.d.: 35). Dr Peter Fitzgerald, the founder and managing director, is a chemistry graduate of QUB, and Randox's unique technological capabilities have been developed in networking arrangements with university laboratories. For example, the Northern Ireland Semiconductor Research Centre fabricates the unique integrated circuits that are co-designed with Randox. The Centre has a versatile research laboratory, rather than a dedicated chip plant, and has done leading research in direct silicon wafer bonding technology.

***Kainos***

Kainos, a software design company with proprietary programs, has grown at 25% per year for over a decade and employs 200 people. Half owned by Queen's University Business and Industrial Services (QUBIS) Ltd (a high technology holding company of Queen's University, Belfast (QUB)) and half by ICL/Fujitsu, Kainos is the largest of 18 spin-off companies from QUB.[61] In the beginning ICL, in an agreement that included supplying QUB with a new mainframe computer, became a co-owner of Kainos and supplied the first three projects. This enabled Kainos to concentrate on technologies and people; the marketing was left to ICL, which distributes around the world, and building space was provided by QUB. Kainos' most successful product, a document management system, one of three winners amongst 40 entrants in a Microsoft competition, led Microsoft to enter into an alliance with ICL to form a solution software centre in Northern Ireland to be jointly run with Kainos.

Kainos has opened an office in the RoI which, according to managing director Frank Graham, has 'the second best IT infrastructure in the world'. Like Silicon Valley and Route 128, Ireland's virtuous circle of regional growth dynamics acts as a magnet to emerging innovative companies in information technologies.

But given its strong academic history in software design and computer science, the number of software companies in Northern Ireland is strikingly small.[62] Insiders estimate that

[61] *For a description of QUBIS Ltd, set up by Queen's University in 1985, and the 15 enterprises it has fostered, see Cartin (1996; 1998).*

[62] *Professor Tony Hoare, now of Oxford University, is widely considered to be one of the three or four top intellects in the history of UK computer software design (McLean and Rowland, 1985). He taught and researched at QUB in the early years of his career and left his imprint in software design capability and well-trained students.*

approximately 10 'world facing' software companies have headquarters in Northern Ireland with another 70 software companies that are 'Ulster facing' in their marketing orientation.

The skill base cannot explain the lack of entrepreneurial firms in software. Webforia, a software startup company with headquarters in Redmond, Washington State, located in Northern Ireland because of the 'hard development software' team that it could put together which Brian Cassidy, a co-founder (and educated in Northern Ireland), claims would rival any team anywhere.

***Seagate***

Seagate has developed a local R&D capability to upgrade the disk drive chip-making processes in Northern Ireland that could evolve into new product development capability. The Seagate Corporation has fully developed systems integration capabilities and follows a similar strategy to Intel of integrating R&D and manufacturing.

Seagate shows the difference between MNCs that bring employment and those that transplant capabilities with the potential to trigger local growth dynamics. Since coming to Springtown, Seagate has built up a strong R&D capability in conjunction with a Research Consortium in advanced materials involving 4 research laboratories at QUB and the UU. Seagate's Springtown R&D Centre now employs 30 people but has plans to expand to 100 in the next few years. But Seagate is not simply harvesting science and engineering graduates, it is planting seeds for advanced skills. For example, Seagate sponsors 4 research graduate students for each academic year. A range of university lecturers from various related disciplines (physics, electronics, computing, chemistry, engineering) and 12 sponsored students, have visited Seagate's labs in Minneapolis. Dr Aric Menon, Vice President of Seagate Research, is an Honorary Professor at both universities. The research in advanced materials in general and in magnetic recording specifically will form a skill base important to many industries. QUB is now offering a master's course in materials science that aims to meet the needs of Shorts, Harland & Wolff, and AVX as well.

Seagate illustrates the industry/university partnering that constitutes the regional innovation model developed in high tech regions. These partnerships are crucial for shaping the skill formation process and linking innovation to regional growth. They underlie the industry/university dynamic in which specific and advanced technological knowledge are simultaneously created and expressed in both unique company capabilities and the university curricula. These provide a basis for regional diffusion of advanced skills.

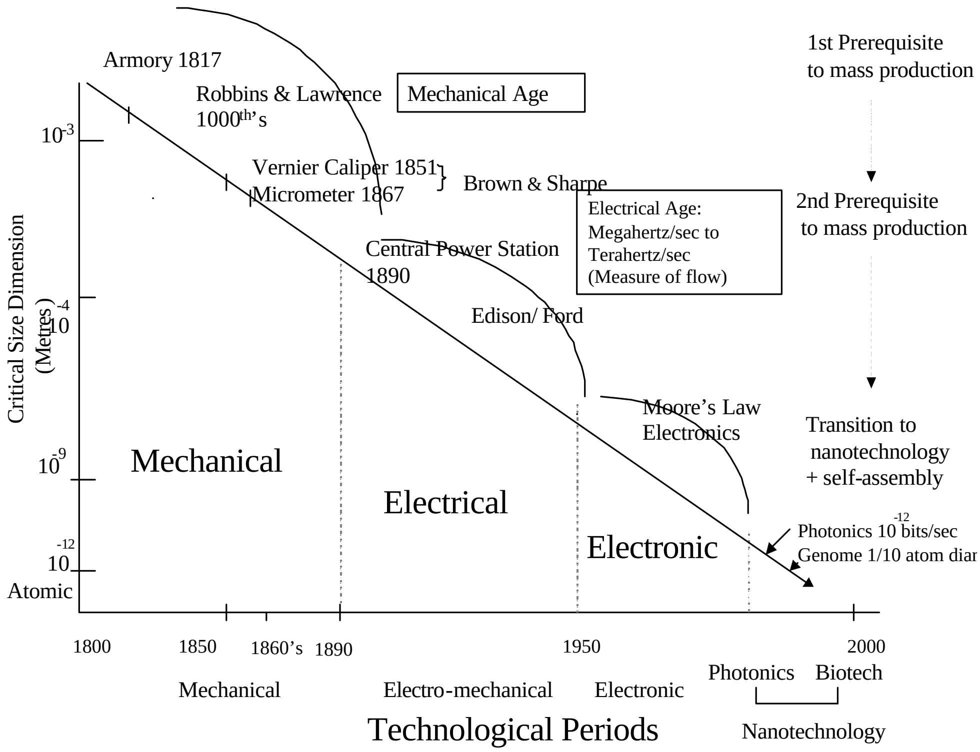
***Nortel***

Nortel is a Canadian based, world leader in fibre-optic switching and transmission systems equipment R&D. This means that Nortel is on the cutting edge of the transition to nanotechnology captured in Figure 9. The Monkstown manufacturing facility is co-located with Nortel's Northern Ireland Telecommunications Engineering Centre (NITEC). NITEC employs over 300 people (a tenfold increase from 1988), mostly graduates, in the province's largest R&D facility. NITEC has built up a substantial capability in product development and technological innovation for optical network products, including digital processing, multiplexing equipment, and telecommunication network management. Nortel was a pioneer in systems integration and design modularisation in the telecommunications industry, with specialised technological knowledge in integrating product systems with country-specific communication protocols.

Nortel has always been closely involved with tertiary education in Northern Ireland. Academic staff at the Digital Signal Processing Laboratories (DSiP), for example, do research on the rapid design of integrated circuits for telecommunications, multi-media, and broadcasting applications which bridges the fundamental research activities of electronics engineering at Queen's University with research applications at Nortel. Product technicians with skills in testing and diagnosis are also critical to the facility; they tend to be graduates of colleges of further education. Nortel hires software people which it trains in hardware, as well as the other way around. Nortel maintains a substantial product development centre in Northern Ireland because of the capabilities that have been built since its takeover of Standard Telephone and Cable's facilities in the mid-1980s. Its Montreal facilities are less well placed for working closely on product development and transmission management systems with European customers. This includes network design, network installation, and pre-installation testing. But Nortel has invested heavily in product design and development capabilities, including prototyping, design for manufacturing and rapid new product development in its Northern Ireland facility. Modular design, for software and hardware, is critical to driving down the development cycle from 24 to 18 to 12 and increasingly 6 months. The competitive advantage of the plant is not in manufacturing costs for standardized products.

**FIGURE 9**

**The Evolution of Precision Machining**




Contract manufacturers specialise in such facilities, which are highly footloose.[63]

Nortel has won the UK Quality Award (as well as BT Northern Ireland) and is making the transition to self-directed work teams. The next step in late 1998 was to move to multi-functional work teams. Many of its processes are benchmarked with 'best in class' internationally. The company is vision-led and emphasises a 'town-hall' approach as the best method of communication. Top officials meet with employee groups of 40-50 three times a year to elaborate the company's vision. Nortel has approximately 200 local suppliers, but 40 enjoy roughly 80% of the business. BEMAC, a local supplier of sheet-metal products, is on Nortel's international approved vendor list.

63 *In the words of Alan Bowers, Nortel's Business Planning and Benchmarking Manager: 'Products with no technology involved can be lifted and moved tomorrow' (interview, December 2, 1998).*

### *Techno-diversification*

The degree of techno-diversity in Northern Ireland's industry is limited. The industrial organisation of Northern Ireland has been dominated by a combination of a few large, vertically-integrated enterprises and small firms that supply the local market. Without entrepreneurial companies, techno-diversification has been limited; without techno-diversification and new firms, industrial speciation did not occur and the region became further locked into the traditional industries and skills; without new industries, skill formation was stalled, both in the formal and informal education systems.

Consequently, the region does not have the inter-firm and extra-firm infrastructure for dynamic industrial districts of the 'third Italy' type. The growth dynamics of such districts depend heavily upon the decentralisation and diffusion of design capabilities, high degrees of techno- and micro-diversity, and open systems for easy inter-firm networking.

From the growth dynamics perspective, a growth path dominated by a few firms has both a positive and negative side. The positive side is that such growth economises on scarce managerial talent and gives powerful direction from top to bottom of a single enterprise. The negative side can be explained in terms of barriers to internal and regional growth dynamics from dominant enterprises organised in a top-down hierarchy.

G.S. Checkland has used the metaphor of the upas tree to capture the syndrome of decline in Glasgow, a syndrome which was built into the causes of its success:

> Conditions external to Britain were changing in an irrevocable way: her share of world trade and of shipbuilding was rapidly diminishing. Clydeside was thus confronted with creeping obsolescence on a massive scale. In regional terms, the old structural problem deriving from Victorian and Edwardian times was still there. The upas tree of heavy engineering had killed or discouraged the growth of other industries of a more modern kind beneath its massive and intertwined branches; now the upas tree itself, so long ailing, was decaying, its limbs falling away one by one. Not only had it been inimical to other growths, it had, by an inversion of its condition before 1914, brought about limitation of its own performance. (Checkland 1981: 48)

The legendary upas tree was believed to have the power to destroy other growths for a radius of 15 miles (Checkland 1981: i). For Checkland, the upas tree represented a few firms in a few industries and the associated skills that long dominated the economy and industrial policy-making in Glasgow. The unintentional side effect of an industrial policy to preserve firms can be to build barriers to the emergence of change agents, including new business models, techno-diversification, and industrial 'speciation'.

The upas tree effect can be particularly devastating at a time in which transformational growth offers the greatest opportunity. This is a time when maintaining a region's competitive advantage depends upon making a transition to new principles of production and organisation.[64]

### *Networking*

Open-systems networking operates on only a limited scale in Northern Ireland. This, in turn, limits regional capabilities for new product development and innovation. Furthermore, the limited depth and breadth of networking capabilities increases the barriers to entry for specialist firms.

A number of world class machining and tooling firms serve the multi-national corporations, such as Moyola, which collectively offer the range of activities required for new product development capabilities. However, in contrast to regions with a critical mass of firms pursuing design-led strategies, the breadth of specialist companies in feeder industries is limited in Northern Ireland. If this heritage were to be run down further, the industrial future of Northern Ireland would be in question because of the mixture of formal, technical and tacit skills in such firms.

Companies in the light industries such as clothing, metal working, machining, and furniture face a dilemma that demands a collective response. The pattern in UK light industries has been one of sub-contractors to retailers who pursue economies of scale and enjoy considerable market power. On the one hand, such companies can partner powerful retailers to reach large final goods markets. On the other hand, the extraordinary market power of UK retailers is an obstacle to the process of establishing design-led, open-system models of industrial organisation.

UK manufacturing firms, even though small in size, do not specialise by capability or choose partners with complementary capabilities; instead, they seek to master a range of capabilities, ineffectively. Not surprisingly, the fragmented (non-networked) character of UK firms in these industries has left them ill-equipped to compete against networked groups of companies enjoying the industrial district model common in western Europe. The micro-diversity in such industrial districts is a boon to new product development, new technological combinations, and technological diversification. UK companies, in contrast, are not design-led, have not pursued skill formation partnerships and, not surprisingly, have not been receptive to the integration of software and hardware or information technology and production.

However, the aerospace industry, led by Bombardier-Shorts, offers an example of an emerging open-systems model of industrial organisation. Shorts, established as a balloon maker in 1901, received the first volume production order for aeroplanes from the Wright brothers in 1908. Shorts moved to Belfast from Bristol in 1937; it was nationalised in 1943, and privatised in

[64] *The decline can be explained in terms of the idea of competitive system developed in Best (1990) as follows: the leading industries of Belfast, and Glasgow, were organised according to principles of production and organisation that became obsolete with the emergence of a New Competition elsewhere. The new principles, mainly mass production and the organisational innovations associated with, first, the central office functionally departmentalised and, later, the multi-divisional form fostered an order-of-magnitude increase in performance standards. Managers in the 'Old Competition' saw the problem in terms of wages and labour discipline; they sought lower wages and government subsidies. The problems, however, were organisational; a business model had emerged elsewhere that could achieve higher productivity and support higher wages. No amount of wage reductions or government subsidy could address the root of the problem. Industrial policy, too, became the management of decline, an ultimately hopeless task.*

1989 when it was acquired by Bombardier, a Canadian snow-mobile firm that has become a major supplier of rail passenger carriages and the third largest maker of civil aircraft (though a distant third behind the leaders).

Shorts today specialises in the manufacture of engine nacelles, the pod that holds jet engines, which it supplies to all jet engine manufacturers. It also specialises in the composite, carbon-fibre technology used in fuselage construction, and landing gear doors. As part of the Bombardier Group, past activities in missile air defence systems have been transferred to Thompson-CSF.

Aircraft and aeronautical design activities at Shorts illustrate how decentralisation of design can accompany integration into global production networks. While Shorts is no longer responsible for design of whole aeroplanes, it has a unit of 400 design engineers who are integrated into Bombardier Group's design engineering capabilities. The Belfast group is involved in the overall concept stage and then takes responsibility for the design of the parts of the aeroplane which they manufacture, mainly fuselages and nacelles.

Shorts is developing two capabilities critical to its new role: a responsive, short cycle- time supply base and 'six sigma' quality system. Both these activities involve moving up the production capability spectrum to higher technology management capabilities and the diffusion of world class manufacturing capabilities to a supplier base which, in turn, will create new opportunities both for suppliers and firms in other sectors that use the same supplier base.

Present networking partners include Moyola Precision Engineering, Langford Lodge Engineering, and Huddleston Engineering which supply components and tooling; Project Design Engineers which designs testing rigs, tools and special purpose machinery; Mallaghan Engineering which designs and manufactures aircraft ground handling systems; Denroy Plastics which supplies injection moulded components; Martin-Baker, a global market leader in ejection seats; B/E Aerospace (US) which designs and manufactures business class seats; RFD at Dunmurry which designs and makes life rafts, lifejackets, and aircraft recovery systems; Ewart Liddell, Ulster Weavers, and Club Herdman which supply linen napkins, headrests, and towels; and Active Multi-Media which designs web sites and searchable databases for executive jet services companies.

This system of alliances and partnerships is, however, the exception in Northern Ireland. Not surprisingly, given the limited sectoral and technical diversity, networking has been limited.[65] The size of the supplier base is also limited which, in turn, will limit growth potential unless there is a diffusion of world class practices to a much wider range of companies.

**Production Capabilities**

Chapter 2 developed the links between production capabilities, including technology management, and enterprise performance standards (see Table 1). The sectoral transition diamond (see Figure 5) indicates the development of a region's or nation's production

[65] *The Northern Ireland Growth Challenge's Engineering 'cluster team' has organised a group of 11 suppliers to the aerospace industry into an 'association' which could become a model.*

capabilities and models of technology management. Each pole is associated with the production capabilities required to achieve competitive advantage in a distinctive set of products. Movements of the diamond in an upward and left direction represent a shift of resources from less technology- and skill-intensive sectors to more complex and knowledge-intensive applications. Such reallocations involve transitions to technology management capabilities based on more advanced principles of production (from interchangeability, to single product flow, to multiple product flow and systems integration). Lack of movement over time in the sectoral composition suggests limited organisational change capability at the regional and enterprise levels.

Rapid industrial growth can be depicted in terms of a movement of the diamond away from unskilled, labour-intensive activities and sectors (bottom corner) and raw material, scale economy activities (right-hand corner) to skilled labour, complex production process activities (left-hand corner) and knowledge-intensive sectors and activities (upper corner). An organisational X-ray of successful transitions captures movement along the production capabilities spectrum shown in Table 3 and the development of regional technology management and innovation capabilities.

Regions in which knowledge-intensive activities, firms and sectors are the drivers of growth (the north pole in Figure 5) have a range of common regional capabilities. These include systems integration (starting with hardware and software), open-systems networking, industry/university partnering models for integrating product development and R&D, decentralisation and diffusion of design, and technological diversity and new firm creation (see Chapter 2). A similar examination of complex-process production activities at the west pole reveals a range of management practices and organisational capabilities such as flow analysis, cellular manufacturing, and self-directed work teams, and a performance measure that enhances the production objectives of cheaper, better, faster, and more flexible.

Northern Ireland industry is heavily biased towards the south and east poles.[66] There are a few firms in the west pole deploying complex production activities, particularly ones involving high volume, mixed production processes.[67] A limited number are in the northern segment of knowledge intensive sectors. The implication from our previous discussions is clear: Northern Ireland's industrial future depends upon building capabilities to support production in the northern direction. This is the region of systems integration, design integration, low volume production activities that can build a competitive advantage in knowledge intensive activities.

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66 *In the food processing industry, a number of companies that supply leading distributors such as Tesco and Sainsbury's are under pressure to introduce product extensions on a regular basis. These companies, however, are not growing rapidly. Instead, they face commodity market conditions and have limited unique capabilities. This means limited productivity.*

67 *Desmonds, a supplier of 12.5 million garments a year for Marks and Spencer, has made the transition to PS 3. In the words of Dennis Desmond: 'In the old days, around 10 years ago, it took three to four weeks from the fabric coming in until a finished garment was dispatched. Now it takes three to four hours' (Financial Times, March 21, 2000, p. III). In fact, Desmonds could well be an entrepreneurial firm. The company's Northern Ireland plant specialises in innovative fabrics in a short lead time production capability. While the industry was shrinking in Northern Ireland, Desmonds' grew by 10% in 1999.*

This sector is critical to Northern Ireland's industrial future, given the region's small size and its technological heritage. But policies designed to enhance the 'knowledge-driven economy' must by grounded in what companies actually do and what capabilities they actually have, individually and as part of regional systems, and what capabilities they can develop.

The lack of sectoral change over time is a reflection of limited movement up the production capabilities spectrum. Company visits suggest that, while many plant managers are aware of aspects of world class manufacturing practices, few have first-hand experience in observing such practices or have been involved in modernisation programmes.

Even plants that are supplying multi-national companies rely upon out-dated quality programmes and plants that have not been reorganised according to processes instead of functions.[68]

At present, the requisite capabilities for a knowledge-driven industrial system on a scale to drive a high rate of growth are lacking in Northern Ireland. The challenge is to develop such capabilities; without them, breakthrough innovation may occur in university research centres and new high-tech firms may well emerge in science parks, but they will not be part of regional growth dynamics.[69] They will be peripheral to the forces that shape the industrial future of the region.

Making such transitions is not easy.[70] The rapid pace of introduction of technologies in the success stories is a consequence of the prior or simultaneous development of a specific set of

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68 *This is changing. In 1998 the IDB commissioned a pilot project using the 'theory of constraints' approach to management (process integration and bottleneck analysis) aimed at 'improving throughput, reducing work-in-progress and enhancing margins' and a training programme organised at the University of Ulster at Jordanstown at which 30 companies attended. For other such examples including benchmarking and strategic alliance initiatives, see IDB (1999).*

69 *The Cambridge Phenomenon in East Anglia suggests that science and technology parks around a world class university can foster an industrial district of high tech firms. But on the negative side, the Cambridge Phenomenon has not driven regional growth dynamics (see Figure 2). Techno-diversification, inter-firm networking, and industrial speciation have been limited. Cambridge in the US, as part of Route 128/495, has been associated with both powerful regional growth dynamics and transformational growth to PS 5 (Table 1). The RoI has used manpower planning in information technology to nurture north pole regional dynamics in which multinational firms have played a significant role in generating local techno-diversity and inter-firm networks. For a description of the Irish software industry, see O'Gorman et al. (1997).*

70 *The transition to the open-systems business model and associated entrepreneurial firm start-up system in 1990s' United States was engendered by market pressure from the superior performance of the Japanese kaisha-led PS 4 production system. Firms were forced to restructure and downsize which, in turn, created opportunities to grow new enterprises organised according to the new principles of production and organisation. At the same time, the transition to self-directed work teams increased the integrative skills, and therefore managerial skills, of the workforce. Here, downsizing pressures and multi-skilled, problem-solving workers combined to foster the emergence and growth of small firms. Public policy contributed, as across the country states pursued polices that made it easier to start and develop new business enterprises. The MIT example is a case study of techno-entrepreneur creation in emerging technologies. Such unintended industrial policy helped Massachusetts considerably.*

production capabilities. Rapid growth in recent times has meant regional diffusion of the capability for rapid absorption of technologies. This capability, however, is a consequence of applying the principle of multi-product flow (driving down cycle times) first in production and second in new product development. But making the transition to multi-product flow requires the development of corollary organisational capabilities (variously named *kaizen*, continuous improvement, high performance work organisation, total quality management, self-directed work teams, and plan-do-check-act). This means considerable investment in skill formation to achieve the requisite performance standards.[71]

An informal audit (based on a series of shopfloor tours) of production capabilities in Northern Ireland reveals a limited number of firms that have developed the principles of flow, multi-product flow, or systems integration. The contrast between foreign-based and local firms is evident in plant visits. Inward investment enterprises that compete on the basis of rapid new product development and disruptive innovation are enterprises that have developed technology management capabilities and which require advanced skills. Systems integrators like Nortel and Seagate are examples in Northern Ireland. Examples elsewhere include rapid cycle time assemblers like Dell and Toyota; fast new product development cycle time competitors like Motorola; and fast innovators like HP. These enterprises have strong internal pressures to build networking alliances to supply parts and components. Unfortunately, few such enterprises have been established in Northern Ireland.

High performance work systems are virtually non-existent, with the exception of a number of software development firms such as Kainos and a select few foreign enterprises such as Du Pont, Nortel, and Seagate. Some locally-owned firms that supply transnational firms have begun the process of developing cellular manufacturing and self-directed work teams. High throughput (short cycle-time) capability can be measured in terms of high inventory turns (sales divided by inventory), rapid response rates, and short delivery times. The great majority, however, are organised in terms of batch production, high inventory systems, and Taylorist, supervisor-centred work organisation. Product-led competition will not become part of the industrial landscape until a critical mass of firms emerges with the high throughput (or short cycle-time) production capabilities to produce multiple products on the same line and a work organisation with the capability to design quality into the production process.

The quality performance standard can be measured by defect rates or by international quality assessment exercises. Here, too, there are Northern Ireland success stories but too few to effect growth. Northern Ireland has approximately 23,000 VAT registered firms. Over 80% of these have less than 10 employees. Bob Barbour, Director and Chief Executive of the Northern Ireland Quality Centre, estimates that as many as 70% of these would not score more than 150 points when benchmarked against the 1000 point score of the European Business Excellence framework. Perhaps 3-4% would score between 400-500 points and 25% would score somewhere in between. Only a few of the larger private sector organisations have scored over 600 points, which puts them among the best in Europe.

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[71] *Unfortunately, the issue of 'on the job' skill formation is not taken up in the vision statements. A 1978 household survey showed that two-thirds of the workforce had vocational or higher qualifications in Germany, against one third in the UK. See National Economic and Social Council (1992: 123).*

[72] A comparative study of the quality capabilities of small firms in Northern Ireland and Massachusetts by Nola Hewitt-Dundas (1997) suggests a substantial gap across four sectors.[73]

Short cycle times in *production* and quality capabilities are, in turn, a precondition for integrating design and manufacturing and becoming a short-cycle time competitor in *new product development.* The success of Desmonds illustrates the point. Desmonds has not sought to maintain a competitive advantage in the production of commodity fabrics but in the 'manufacturing base to produce new, innovative fabrics' (*Financial Times*, 21 March 2000, p. III). Rapid new product development rests upon a production foundation of short cycle time and high quality performance.[74]

Upgrading technology management capability is the next step. Unfortunately, it is not considered a powerful resource for growth in most Northern Irish business enterprises (or policy documents). But technological advance is the most powerful driver of growth and technology management is a means of converting the world's vast pool of technological and scientific knowledge and experience into improving production capabilities and productivity.

The major reason for the lack of attention to technology management stems from the lack of high performance work systems. Technology management depends upon such practices. Exhortation by policy-makers to firms to become more innovative cannot be acted upon by enterprises that lack technology management capability. Likewise, managers with an appreciation of technology still depend upon technology management capabilities to turn technology into a basis for competitive advantage. The knowledge economy offers great opportunity, but it will not drive economic growth without attention to production capabilities.

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72 *In order to improve this situation, the Northern Ireland Quality Centre has developed a specially customised scheme for SMEs under the title, 'Pathways to Excellence' based on the European Business Excellence framework. Under the scheme, recognition is granted to firms when they reach three distinct phases of improvement. Finally, when a score of 400 has been achieved the company may apply for public recognition and the 'Mark of Excellence'. This puts the organisation on a database of excellent companies at a national and international level. Firms that are currently in the 400-500 score range have a self-assessment capability to measure and track their performance continually against world-class standards. By June 1998, the Northern Ireland Quality Centre had assisted 15 companies up to the 400-point level. By the same time, 1218 firms in Northern Ireland were ISO9000 registered. The current ISO standard equates to approximately 150-200 points against the European Business Excellence framework. These numbers and information are from an interview with Bob Barbour (June 10, 1998) and an update by e-mail correspondence March 30, 2000.*

73 *Hewitt-Dundas's research included metal goods, mechanical engineering, electrical and electronic engineering, and food processing. Of Massachusetts' small firms, 100% had developed quality control systems ('during production') in three of the four sectors and nearly 90% in the fourth. Measures of their Northern Ireland counterparts ranged from a low of 22% in mechanical engineering to a high of 67% in electrical and electronic engineering. Only 33% of metal goods and 40% of food processing firms in Northern Ireland incorporated quality control into the production process (1997: 198).*

74 *The following quotation from Dennis Desmond is an example of how an entrepreneurial firm identifies a market opportunity and builds the production capability to respond: 'A retailer's biggest problem is availability. There is a need for manufacturers to develop a highly responsive system . . .'*

## Skill Formation

### *Industry/Higher Education Innovation Dynamics*

Northern Ireland's educational system offers a basis for competitive advantage with considerable potential. Few regions in the world of the size of Northern Ireland have the range of university level disciplines in engineering and science-related areas, particularly in information technology.

Its university system can boast world class research facilities in several areas. The Digital Signal Process Centre, for example, at QUB has spun off a successful start-up business and works closely with Nortel at the cutting edge of a technology with a huge growth potential. Likewise, biomedical science at the UU, which includes research activities in biotechnology, human nutrition, cancer and aging, diabetes, radiation science and vision science obtained the highest possible 5* in the 1996 Research Assessment Exercise, 'the highest ranking in terms of size and rating out of 68 UK universities in this highly competitive area' (McKenna, 1998: 6).

Shorts has a long and close 'partnering' relationship with higher education. While six units of QUB achieved a grade 5 for the 1996 Research Assessment Exercise, only the 15-person Mechanical, Aeronautical and Manufacturing Engineering Department achieved a 5*. The industrially-funded Shorts Chair and its secondment of a senior Vice President of Shorts to the Department suggest a strong industry/university partnership in aerospace.

These examples, added to the entrepreneurial firms described above, attest to the existence of the science and engineering research base vital to developing a competitive advantage in knowledge intensive capabilities in Northern Ireland. At the same time, however, of the more than 25 Northern Ireland research and development centres, relatively few have active industry/university partnerships and a sizable number do not have active student involvement.[75]

A notable exception is Queen's University Environmental Science and Technology Research Centre (Questor). Its mission statement reads as follows:

> The Queen's University Environmental Science and Technology Research Centre (QUESTOR) is an industry/university cooperative research centre carrying out fundamental and strategic, integrated, multidisciplinary scientific research in selected critical aspects of environmental science and technology. The research programmes seek to provide understanding aimed at finding cost-effective solutions to environmental problems allied to encouraging industrial endeavour and minimising environmental impact.

The main focus of research is on techniques for effluent clean-up and clean technology. The range of projects, the active involvement of 21 companies, the opportunities for students, and the international links are all impressive. The member companies range from manufacturers of

[75] *See IRTU (n.d.) for a directory and description of Northern Ireland research and development centres.*

pharmaceuticals, chemicals, instruments, textiles, and beverages to suppliers of electricity and water. The Centre is also an innovator in developing a methodology to facilitate environmental technology transfer to small and medium-sized firms. A major attraction to companies is the interdisciplinary character of the research that enables a company to network with expertise otherwise hidden away in disparate departments. Projects have involved university staff from the following departments working together: agricultural chemistry, chemical engineering, chemistry, civil engineering, computer science, microbiology, and psychology. The Centre has brought into the university state-of-the-art testing equipment, some of which does not exist in even the most well equipped industrial laboratories.

Questor is a model in terms of university responsiveness to companies designing research projects in a way that preserves a university's commitment to the openness and public nature of knowledge creation and diffusion.[76] This gives students the opportunity to work on projects that are industrially relevant, cutting edge, and publishable. For these reasons Questor has a mix of post-doctorates, PhD candidates, and undergraduate students involved in industry-funded, university-supervised research projects. In addition, the model enables researchers in companies to work and network with a broad community and advance the technology management capabilities of their companies. Finally, Questor is currently developing a programme involving partnerships between companies and primary school teachers to address the lack of students opting for science and engineering courses.

Here Northern Ireland has a best practice model. Industrial policy funding which goes to companies to support industry/university cooperative research programmes has a potentially huge upside: it addresses the lack of technology management and innovation capabilities in Northern Ireland industry. It has a very limited downside: capabilities are advanced even if the participating companies fail, and students are provided with opportunities that can only enhance their career prospects.

The problem is that while the success stories of industry/university partnering have been market tested, they are not widely diffused.[77] The size of the IT programmes at UU and QUB are particularly impressive and are a magnet for IT companies given the global shortage of skills in this area.[78] The opportunities for industrial policy are considerable.

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[76] *Questor, founded and run by Professor Jim Swindall, is the first European industry-university co-operative environmental research centre in Europe modeled along the lines of the US National Science Foundation's Industry-University Cooperative Research Center programme; in fact, it is the only non-US centre in the programme (see IRTU n.d.).*

[77] *For an excellent summary of university and industry collaboration in Northern Ireland see. Beatty (1997). Beatty is the director of the Northern Ireland Technology Centre, QUB, which has many of the features of Questor in equally relevant technological areas including factory automation, CAD, product design, rapid prototyping, and instrument calibration.*

[78] *See Hughes (n.d.) for a description of the size of educational programme and infrastructure of IT in Northern Ireland. See also Software Industry Federation (1998). For the RoI, see FAS (1998). Two other important documents are Irish Software Association (1998) and Horn (1998). Dr Chris Horn is Chairman/CEO of IONA Technologies Plc., and chair of the Expert Group on Future Skills Needs.*

The potential is equally great, and unmet, for collaboration in skill formation between companies, existing and emerging, and the colleges of further education. These colleges enjoy little guidance in manpower development planning. They are, however, aware that their counterparts in the RoI have played a major role in advancing the Capability Triad of advanced technology management capability, new business models, and skill formation that have enabled sustained growth.

***Skill Formation and Growth Dynamics: Lack of Manpower Planning***

The domain of 'manpower' planning is a striking omission from government vision statements in Northern Ireland: high growth without a complementary skill formation capability has never occurred in productivity-led growth.

The story of every successful rapid and sustained industrial growth experience is simultaneously an account of the pro-active and strategic institutional development of visible and invisible colleges of knowledge diffusion. Business enterprises harvest the crop of new graduates; educational institutions, funded largely by the government, plant and cultivate the crops. The challenge is to integrate the two into a single process that respects the common good features of education. This demands a supply of 'economic virtue' or 'social capital' in which the common good is politically negotiated. The skill formation system is immobile; it is a critical capability shaping a region's competitive advantage. Undermining the skill formation system is simultaneously to reduce regional career opportunities and to place limits to growth.

The UK Department of Trade and Industry's *Competitiveness White Paper* notes that the large and growing global skills gap in IT has 'one notable exception . . . Ireland, where the ICT industry - which on a per capita basis is the same size as the UK's - benefits from an annual output of Electronic Engineering graduates at three times the UK level' (DTI ,1998: Appendix, part 8). The RoI has achieved the NIGC goal of 'fastest growing region in Western Europe' with manufacturing output increasing nearly 5 times that of Northern Ireland over the 1993-1998 period (*Strategy 2010*: 58). In an excellent example of manpower planning in a growth industry – '*Building on Ireland's Skill Opportunities'*, a reference is made to over 70 studies on 'employment projections and skills needs have been carried out in recent years' (Horn, 1998: 6). Horn argues that 'The skills issue is one of the most critical facing the economy'.

Chris Horn writes there that the high growth scenario will demand 8300 annual technology graduates and lays out four strategies for achieving the goal. The current annual supply of technology graduates (1997-2003) is projected to be 5400 in the RoI of which 3100 are degree level professionals and 2200 are diploma/certificate level technicians (Horn 1998: 9).[79] In comparison, the supply of IT graduates from QUB and UU will average about 825 and from FE Colleges about 1000 over the 1997-2001 period, roughly a quarter as many at degree level, and a third of the total, as in the RoI (Software Industry Federation 1998: 9).

[79] *The 5400 includes 'the Government's plan announced in March 1997 to substantially increase the numbers of engineering technicians (+750 new entrants annually) and computer professionals (+1000) (Horn, 1998: 9).*

The high growth scenario is costly in the short term. For example, to increase the number of professional graduates by 400 would require 2120 new degree places which, at a student to staff ratio of 21 to 1 would require 100 new teaching positions. But measured in lost growth opportunity, the failure to make the investment is the truly high cost scenario.

***Process Integration and Manpower Planning***

Skill formation is a multi-activity process that can be subject to the process improvement methodologies that have been developed to enhance flow within firms and along the supply chain in world-class manufacturing. It means that all the activities required to convert a raw material into a final product must be linked in order to capture the interrelationships. Linking the activities into a single process focuses attention on the linkages along the supply chain. It is the first step in rethinking and redesigning the process to improve it.

While procedures have been developed for integrating processes which involve material flow along the supply chain, the development of skills has remained fragmented and the linkages unattended to. Skill formation is a process involving numerous activities that are rarely integrated into a single process. This lack of integration locks the demand and supply of skills into place; each reinforces the other as the supply of skilled labour matches the demand to preserve a steady state. But the lack of integration is a critical barrier to growth. Growth demands a lock-step increase in supply and demand for specialist skills. This requires redefining the institutional relationships by which supply and demand are coordinated.

Process integration of skill development is the domain of manpower planning techniques. But successful manpower planning depends upon process integration. Moving from a disintegrated pattern to an integrated process is about the development of supply chains for skills. Not surprisingly, the inter-relationships are often ignored and usually obscured. Like the old model of manufacturing, functional departmentalisation leads to shifting blame instead of improving flow. Advancing the rate of skill formation and defining the precise combination of generic and specialist skills requires process integration and simplification across activities involving employers, teachers at all levels, and education authorities. Without the bottom-up, close-to-the-road, tacit knowledge which can only be supplied by practitioners, the most sophisticated planning exercises will lack the inputs required to make them work. Thus, here again, the transition to high growth depends upon developing the organisational capabilities to embed advanced techniques.

The development of integrated manpower development programmes can be an important source of regional competitive advantage. Skill pools and schools are local, immobile resources. Furthermore, graduates from regional colleges and technical schools around the world tend to remain in the region. The industrial development role of the regional college or university involves responsive collaboration with industry and government in skill formation appropriate to that region. The fact that investment in skills takes time and strong relationships that cut across educational institutions and business enterprises means that they cannot be easily replicated.

***Teaching Teachers in the Invisible College: An Example from Japan***

Mission-driven organisations can affect growth by fostering a region's invisible colleges. Industrial transitions, in particular, can be fostered by mission-driven intermediary institutions (neither business enterprises nor government agencies) which form integral parts of regional and national business systems. Ignored by much of the industrial organisation literature, these intermediary organisations can be established by industrial policy-makers, by groups of enterprises, or by professional associations.

Looked at from a national or regional perspective, advancing shop-floor skills again raises the issue of the size of the teacher pool. The number of teachers and the appropriateness of the curriculum place limits on the pace of skill formation. Successful programmes have a common feature: teacher training is designed into the programme. The Japanese Union of Scientists and Engineers (JUSE) provides an example.[80] It administers the Deming Prize upon which the Baldrige Award in the United States and the European Quality Award have been modelled. JUSE is a non-profit, mission driven agency established in 1947 to promulgate TQM. JUSE fostered a continuous improvement (*kaizen*) capability throughout Japanese industry. JUSE developed an inter-firm teach-the-teachers methodology that diffused the new management philosophy across industry that had a cascading effect. Workers not only teach one another as part of the flexibility required for multi-product flow production, but the plan-do-check-act methodology became embedded in an inter-firm education system which produced not only workers educated in the new system but teachers. Successful trainees gain certificates which make them eligible to teach to the new generation of workers, often in other companies.

**Conclusion: The Lack of Growth Engines**

Northern Ireland suffers from poor performance in innovation and productivity. The immediate cause is the lack of an enterprise 'culture' often referred to as a 'BMW syndrome'. But the deeper cause is the business model. The prevailing business model, with a number of outstanding counter examples, is not conducive to technological advance and innovation.

Northern Ireland lacks entrepreneurial firms. Few companies are organised for product-led competition. Many firms have been successful in a market niche and are important to the economy of Northern Ireland. These firms are important in many ways but they are not engines of rapid growth anywhere in the world. Entrepreneurial firms, organised in terms of the technology/market dynamic, propel regional growth dynamics and transformational growth to a more advanced regional technology management capability.

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[80] *The Japanese Human Relations Association (JHRA) also specialises in continuous improvement methods. Kaizen tiean is a system for eliciting commitment from every worker to contribute to on-going improvement. While the suggestion box system has long existed in America, it became a powerful organisational tool in Japan, not for eliciting one big idea but for promoting participation. The idea is to institute a concept of work that includes the goal of on-going productivity enhancement through the accumulation of numerous small improvements. A feature of the Japanese variant of the suggestion box system was to give authority for approval and implementation to the front lines. The idea is not to simply make a suggestion, but to implement it. This means educating and empowering work teams to manage the process. Instituting an implementation capability into the suggestion box system made it work, according to the JHRA. The JHRA claims a hundredfold increase in suggestions when the system is properly organised (1992: xiii.).*

Technology management is pivotal to the growth dynamics analysis. Leaders in industrial development have developed new models of technology management, and high growth followers have developed regional capabilities to manage technology. Technology management at the firm level is about developing the organisational capability to manage the technology/market dynamic; technology management at the regional level means fostering the virtuous circle of regional growth dynamics. Both involve policies concerning technology transfer, adoption, adaptation, development, combination, diffusion, and diversification.

Rapid growth involves coordinated organisational change in each of the three domains, business model, production capabilities, and skill formation. The concept of the *Capability Triad* (Figure 1) captures the systemic dimension of organisational change at enterprise and regional production levels. The three domains are not separable and additive components of growth but mutually interdependent sub-systems of a single, mutually adaptive developmental process. The concept of Capability Triad offers a vision for achieving rapid growth in which industrial policy plays a major role.

The lack of entrepreneurial firms is to the capabilities and innovation perspective what the lack of a capital goods sector is to a capital accumulation model of growth. The lack of entrepreneurial firms is a serious obstacle to growth and should be the central challenge to industrial policy. But, as we shall see next, industrial policy in recent years may well have unintentionally contributed to the problem. The emphasis on entrepreneurial firms as the source of growth, rather than capital accumulation, makes policies of subsidising capital investment suspect.[81]

[81] *This sentence paraphrases Richard Lipsey (1993) but substitutes entrepreneurial firm for innovation as the source of growth. From the capabilities and innovation perspective, innovation is an effect of the activities of entrepreneurial firms.*

# 4. THE WAY AHEAD

## Industrial Policy

### *Implicit Assumption*

The challenge for economic policy in Northern Ireland is to assist the transition to a higher performance economy. The challenge is considerable: a low growth, low productivity, low innovation economy has powerful self-reinforcing barriers to change. The challenge has been addressed by a major strategy document: *Strategy 2010: Report by the Economic Development Strategy Review Steering Group* was published in March 1999 by the Northern Ireland Department of Economic Development. The report had been mandated in the Belfast Agreement in April 1998 that stated the Government would make rapid progress with:

> a new economic development strategy for Northern Ireland, for consideration in due course by the Assembly, which would provide for short and medium-term economic planning linked as appropriate to (a) regional development strategy….

*Strategy 2010* involved a wide-ranging process of consultation begun earlier in the decade by the publicly funded NIGC. The goal of the NIGC is succinct: ‘The vision is that of Northern Ireland as *the fastest growing region in Western Europe*’ (1995). *Strategy 2010* seeks to ‘create an economy which is fast growing, competitive, innovative and knowledge-based.’ Other goals of *Strategy 2010* include a doubling of the share of high-tech industries from 2.9% to 6.0% of employment, a 50% increase in exports and tripling of business R&D as a proportion of GDP.

Both strategy documents maintain that achieving the growth goals depends upon the business sector. For example, after listing the ‘critical challenges to the competitiveness of the region’, the executive summary of the NIGC states:

> The key implication…is that, in the absence of any radical initiative by the private sector, in partnership with government, Northern Ireland’s economy will continue to seriously lag far behind the performance of those economies it would hope to emulate. (1995: 2)

*Strategy 2010* shares the same business-led growth perspective: ‘The Steering Group believes that economic growth must be driven by a resurgent private sector in Northern Ireland, supported as necessary by the State’ (1999: 207). Whereas the NIGC calls for a ‘new enterprise culture’, *Strategy 2010* appeals to a ‘resurgent private sector’.

A vision statement links goals to means or processes and policies. The means of achieving the goals, however, are less clear. Given the lack of dynamic business enterprises, how is the vision of high growth to be realised?

The NIGC emphasises clusters.

> Key to this growth is building more dynamic, competitive clusters that drive continuous innovation, up-grading and learning. In essence, it is a vision of a

return to Northern Ireland's heritage of industrial leadership built on hard work, inventiveness and dynamic enterprise.

Clusters are the missing link between the present poor-performing economy and a rapidly growing economy: 'today no truly competitive sectors or clusters [exist] in Northern Ireland' (NIGC, 1995: 6). *Strategy 2010* also appeals to clusters. The implication is that clusters are the engines of growth. But what will drive the clusters?

Both visions refer to a past of growth driven by dynamic enterprises.[82] But this does not address the issue of lack of entrepreneurial firms. The large enterprises that dominated the linen and shipbuilding industry, for example, were global enterprises. But from a dynamic growth perspective they do not offer models of business organisation to drive productivity-led growth and innovation.

The fundamental challenge of an inappropriate business model is not addressed. Instead, the challenge is defined in terms of lack of 'enterprise culture'. Both vision statements share an *implicit assumption*: that the current business model is adequate to drive growth.[83]

***Unintended Consequence***

The British government has pursued an aggressive industrial policy in Northern Ireland in order to foster growth. Regional preferential assistance to industry in Northern Ireland amounts to 5% of manufacturing gross domestic product as against 0.1% in England (Bradley and Hamilton, 1999: 43). Regional assistance to Northern Ireland manufacturing enterprises in the 1990s funded between a third and a half of net capital spending. Regional assistance as a percentage of net capital expenditures for manufacturing in England, by contrast, declined from 3 to 1% between 1988 and 1995 (NIEC, 1999b: 18).

Unfortunately, a deleterious and unintended consequence has dominated the growth effect. The dominant effect of an industrial policy to promote growth in Northern Ireland has been to underwrite a 'risk-averse' business culture, and thereby stifle 'a new enterprise culture'. This conclusion seems to be shared by academic studies, business leaders, and even government industrial policy-makers. The NIGC is blunt in its condemnation of government subsidisation

[82] *Northern Ireland's industrial history includes the likes of Harry Ferguson, the tractor maker, and J. B. Dunlop, founder of the tyre company. The region enjoyed growth during the heyday of the shipbuilding, linen, and rope-making industries but growth was led by input (labour and capital) rather than technology or productivity (capabilities and skills). Like Glasgow, the region suffered the upas tree syndrome (see Chapter 2) rather than enjoying regional growth dynamics (Figure 2). Furthermore, the linen industry was a low-wage industry in its time with a high dependence on child labour (Bardon and Burnett 1996: 66; see also O' Grada 1994).*

[83] *The bottleneck to growth imposed by the prevalent business model in Northern Ireland is understood by much of the business community, even if it is not built into the vision and strategy. Of four growth scenarios presented in NIGC (1995), only one titled 'Rebirth of Enterprise' offers an outcome of self-sustaining growth. This is consistent with the capabilities and innovation perspective; the difference is that the term cluster can obscure an analysis of what a 'new enterprise culture' and 'rebirth of enterprise' are all about.*

of business, which has 'masked' the competitiveness problem and 'fed the insular, risk-averse culture'. The result has been a 'system that constrained innovation and growth' (NIGC, 1995).[84]

The counter-productive effect is captured in a sentence: 'The system that has emerged in Northern Ireland was potentially dangerous, in that it preserved a fairly stable economy whilst effectively *concealing* the reality of eroding competitiveness' (*ibid.*: 10). Certainly, policy-makers are not unaware of the perverse incentive effects of subsidisation of capital investment. *Strategy 2010* notes that the high level of 'regional preferential assistance' to Northern Ireland of £1331 per manufacturing employee compared with £32 for England 'may be a significant cause of the low level of private equity finance found among local firms' (Department of Economic Development (DED), 1999: 114).[85]

The lesson is inescapable. An industrial policy geared to capital subsidisation in Northern Ireland has fostered a state-dependent, reactive business model. The masking of the 'competitiveness problem' by government subsidisation of industry occurred at a time during which new business models were emerging elsewhere (see Chapter 1). Product-led competition has taken the form of rapid new product development capabilities and lean production in East Asia, design-led industrial districts in the 'third Italy' and, more recently, the high-tech regions in the United States organised around the principle of systems integration.

Entrepreneurial firms are critically important because of the role they play in technology management. This powerful driver of growth and central element in most successful industrial policies is strikingly missing from the vision documents in Northern Ireland.

Technology policy and technology research centres are aspects of Northern Ireland's industrial policy but the linear or pipeline model from R&D to product development and production is taken for granted. Receptive linkages between the internal organisation of business enterprises and their capacity to adopt, absorb, refine, modify, upgrade, advance, and integrate technologies are presupposed. The links between business model and technology management are not considered. Instead, the focus is on subsidising new investment *independently of the business model*. In a region dominated by a reactive business model, this policy becomes part of the problem, not the solution. The goals and the means are at odds.

The goals are not the problem. Technological change enjoys prominence in *Strategy 2010* as the second 'key influence on modern economies'. In fact, a target of *Strategy 2010* is to double the share of high tech industries over the next decade. The problem is the lack of connection

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84 *The deleterious effects of 'subvention' in terms of fostering an 'insular, risk-adverse culture', also referred to as the 'BMW syndrome', is developed elsewhere (Gorecki 1997). Examples of academic research include Roper (1993) and Sheehan and Roper (1994).*

85 *A manager of a successful company explained how this culture had penetrated into industry and banking relationships: when the company sought private finance for investment in new plant and equipment its bankers demanded that the company first apply for a government grant before the application would be accepted. The company was in a bind because such applications take months to process thus compromising the market opportunities the investment was intended to pursue.*

between the goals and the means. Subsidising investment in manufacturing enterprises has turned out not to be a means for advancing innovation.

The aversion to technological change in Northern Ireland runs deep in the business community. This problem must be addressed. Everyone favours technological change, in principle, but not as a capability integral to the business enterprise. Technology *management* is not explicitly included among the six cross-cluster programmes of the NIGC nor is it included in the 'suggested agenda for government' (NIGC, 1995: 17). Technology is mentioned incidentally twice only in the summary of 'private sector-led cross-cluster programmes' among dozens of 'initiatives, goals, and key requirements'; both times as external to business operations. Technology management is not addressed in any of the seven cluster programmes with the limited exception of software. Not surprisingly, technological change does not figure in the policy recommendations of *Strategy 2010* either.

How to break with the historic pattern of an economy led by non-dynamic business enterprises is the growth challenge facing industrial policy-makers. The prevailing business model must give way to a model that fosters technological advance, skill development, techno-diversification, and networking, all critical to the virtuous circle of regional growth dynamics.

Chapter 2 sketched an alternative analysis to guide industrial policy. The critical variables are capabilities and growth dynamics. Three types of growth dynamic are outlined: enterprise growth dynamics, regional growth dynamics (Figure 2), and transformation growth dynamics for advancing the region's production system to a higher level (see Table 1). Application of the capabilities and innovation perspective to Northern Ireland highlights five challenges to achieving high growth goals. Each of these challenges must be addressed if the economy of Northern Ireland is to achieve the goal of rapid growth. But the concept of the Capability Triad (Figure 1) implies that they must be addressed jointly. Policies for any one must be consistent with advancing all three elements of the triad: business model, production capabilities, and skills.

## High Growth Challenges

### *Entrepreneurial Firms*

The entrepreneurial firm is the agent of industrial change. The technology capability and market opportunity dynamic of the entrepreneurial firms is the driver of high productivity growth. The first challenge of industrial policy is to institute processes of entrepreneurial firm creation. Why entrepreneurial firms? Because entrepreneurial firms are learning and teaching firms that contribute to technological advance and to skill formation. Equally important, the need is to seize market opportunities and to be able to do so a firm needs technological capabilities. Firms which lack technological capabilities also lack the capacity to anticipate emerging market opportunities.

Different institutional frameworks have emerged to foster the creation and growth of entrepreneurial firms.[86] The *kaisha* variant of the entrepreneurial firm decentralises design and continuous change into the operating units. An American variant is the leadership and design dynamic which combines top-down and bottom-up actions captured by Andrew Grove's 'dynamic dialectic' (see chapter 2) The 'dynamic dialectic' model of business organisation is a 'learning firm' which can drive rapid new product development. 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 capability to pull technologies into production (see new product development section, Chapter 2).

As strong as the *kaisha* model of the entrepreneurial firm may be, it is not a model *process* of entrepreneurial firm creation. To this we turn to the regional growth dynamics model.

The entrepreneurial firm start-up system is particularly strong in the Silicon Valley and Route 128 high tech regions in the United States 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. Most attention has been focused on financial markets as the enablers of entrepreneurial firms' emergence and development. Venture capital and IPO capability are certainly contributors to the high new firm creation rates in both Silicon Valley and Route 128/495. As important as financial commitment is, though, 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.

A business strategy of focus and network (focus on a core capability and partners for complementary capabilities) can trigger complementary regional growth dynamics as illustrated in Chapter 2. 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).

The industrial policy lesson is that vibrant regional growth dynamics provide an incomparable infrastructure for the creation of entrepreneurial firms. Once the inter-firm dynamics are underway, new firm creation is built into the process. Rapid growth and new firm creation feed on one another. Fast growing, technologically driven firms provide the managerial experience critical to its reproduction in yet new firms.

Lacking regional growth dynamics, the biggest policy challenge is to trigger the processes by fostering the first entrepreneurial firms. This is a big challenge. There is no recipe, but different new-firm-creation processes have been successful. The challenge is to *examine the existing process* and identify bottlenecks for the purpose of identifying policy leverage points. Taiwan has created new entrepreneurial firms and new industries *via* state-led science parks that have fostered such firms. Singapore and the Irish Republic triggered the process by attracting foreign direct investment with higher technology management capabilities. Israel has used public and private venture capital funds plus the in-migration of highly skilled personnel from abroad, particularly from the ex-Soviet Union countries.

[86] *See Cooke (1998) for a survey of enterprise support policies in 'dynamic' European regions.*

Foreign direct investment can quick-start the process by introducing new principles of production and organisation to a region. International firms may or may not be entrepreneurial firms. The challenge is to identify firms well advanced on the production capabilities spectrum with technology management and networking capabilities and then to develop institutional means of fostering diffusion of the new practices and triggering the regional growth dynamics.

The example of Kainos is a case study in the emergence of a rapidly growing, locally owned entrepreneurial firm which could provide clues about fostering the new firm creation process. Converting any of these pilot projects into methodologies for diffusion agencies is a crucial industrial policy role.[87] Successful diffusion requires the partnering of industry, government and educational institutions.

Deregulation can be a powerful creator of entrepreneurial firms. The 'gales of creative destruction' force firms to innovate and create novel methods of production.[88] Digital technologies can assist firms seeking to become entrepreneurial firms by facilitating a transition from business models organised in terms of value chains to ones organised around value networks. The value chain metaphor derived from assembly line concepts suited to long product life cycles in which communication across functional departments was routine (not consultative). Digital technologies assist real-time coordination across functions in the form of value networks that blur departmental boundaries, reduce middle management functions, and compress cycle times for new product development. Robust value networks, internally and externally, increase the responsiveness of companies to market opportunities and technology changes.

Finally, the decentralisation and diffusion of design associated with high performance work systems can foster new firm creation. The integration of doing and thinking, of conceiving and executing, of designing and doing in the organisation of work is, at the same time, redefining work to include managerial activities.[89]

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87 *According to a study by the BankBoston Economics Department, MIT graduates have started 4000 companies nationwide. The study claims that in Massachusetts, the 1065 MIT-related companies account for 25% of sales of all manufacturing firms and 33% of all software sales in the state. See MIT: The Impact of Innovation, web page at <http://web.mit.edu/newsoffice/founders>*

88 *For example, British Telecommunications had 120 rivals within four years of opening up of competition in 1991. After an initial period of severe job losses, the introduction of new technologies by rapidly growing entrepreneurial firms is transforming the industry. Combined with the personal computer and internet revolutions, the transition to photonic technologies has led to a proliferation of products, created vast market opportunities and fostered vertical disintegration. Skill formation has also changed. 'I increasingly hire geneticists, entomologists, cosmologists and zoologists', says BT's head of research. He adds, '[a]nd we're going to get more philosophers'(Wall Street Journal, p. A16).*

89 *Much attention has been given, rightfully, to the processes by which universities produce techno-entrepreneurs. However, 'invisible' college graduates create new firms as well. Usually and rightfully, the engineer is the hero in stories of technological breakthrough and advance. But important at they are, engineers are not the only source of technological knowledge. Machinists with no formal training fill the long history of the advance in production capabilities with examples of innovations. In both cases, an entrepreneur is one who sees a productive opportunity - either a market niche or a productive*

### *Open-systems Networking*

Three types of inter-firm relations 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 arms-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 enabled Japan to establish competitive advantage in the consumer electronics industry in the 1970s and 1980s. But the 'open-systems' networking model has proved effective in 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. *Networking capabilities make cluster dynamics work. At the same time, networking capabilities derive from capability specialisation*.

Open-systems networking, as outlined earlier, 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-systems 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.

As the networking capabilities of a region become more robust, that region takes on more the semblance of a collective entrepreneur. The collective entrepreneurial firm is a self-organising change agent composed of networked groups of mutually adjusting enterprises.[90] It is a composite of networking firms that collectively administer the regional growth dynamic processes.

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. Virtually seamless integration across businesses enhances the simultaneous increase in specialisation and integration that Adam Smith identified as the principle of increasing specialisation. The Internet is the new 'invisible hand' but one that assists the creation of entrepreneurial firms and regional innovation.

The Internet drives down the supply chain cycle time to levels previously achieved only by closed networks with unchanging design specifications. This strength of the 'old' just-in-time and captive supplier network, however, did not involve design information. The open-systems

*capability - and matches opportunity to capability by developing a team and forming a company. Techno-entrepreneurs emerge out of the visible colleges; 'practo-entrepreneurs' spin out of the invisible colleges where they have learned of opportunities and/or capabilities that are not being exploited by existing teams or firms.*

90 *See Best, (1990: 207-8).*

protocol of the Internet enables seamless integration of design information across virtually all computer systems and resource planning systems.[91]

The Internet also facilitates the use of advanced information technologies such as CAD/CAM/CAE for collaborative product development processing.[92] But for such product design tools to be effective, the various departments of the enterprise must be internally networked and aligned or process integrated. Otherwise, information technology gives rise to isolated islands of computerisation in which information is proprietary and communication is limited.[93]

Network capabilities also foster innovation. In Chapter 2 we examined the role of techno-diversification in 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 evolves 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 trajectory can create obstacles to technological transition (Christensen, 1997). This explains the role of networks, whereby new entrants can focus on a technological capability and find partners for the complementary capabilities. Regions with open-systems 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.

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 thereby a target for policy-makers seeking to increase entrepreneurial firms.

### *Technology Management*

In his Sir Charles Carter lecture, Richard Lipsey (1993) offered a broad definition of technology that resonates with the capabilities and innovation perspective. 'Technology . . . must be broadly understood as our way of doing things. It includes:

- the products we make and consume

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91 *See 'Adaptec: Getting the slack out of cycle time', Fortune, Nov 8, 1999 for an example of a 'value network' involving internet facilitated partnering across multiple countries.*

92 *CAD is computer aided design, CAM is computer aided manufacturing, and CAE is computer aided engineering.*

93 *Nanyang Polytechnic's Computer Integrated Manufacturing Centre offers a range of manpower development and information technology partnering arrangements to Singaporean companies. Its website is www.technocim.edu.sg. This centre was established as part of Singapore Economic Development Board's Report of the Committee on Singapore's Competitiveness (CSC). The vision, short-term recommendations, and long-term strategies are summarised at www.sedb.com.sg/vision/vi_cs.html.*

- the processes we employ to make products
- the organisations we use to co-ordinate our economic activity; and
- the institutions that provide the background structure to economic activity.'

For Lipsey, the term innovation is the 'process by which these things are brought into being…and we may speak of product innovation, process innovation, organisational innovation, and institutional innovation'. He adds that innovations are constantly changing our technologies.

Lipsey's concepts of technology and innovation are a starting point for the capabilities and innovation perspective. The next step is to integrate technological change with business organisation and production capabilities in order to understand industrial change better. This means putting the technology capability and market opportunity dynamic that drives the entrepreneurial firm at the centre of our analysis. Starting with this dynamic, production, technology management and regional growth dynamics come into focus. Technology management, then, is not a commodity that is bought and sold but a capability that is integral to production and business organisation.[94]

In Chapter 2, five models of technology management were developed, each explained in terms of an underlying principle of production and organisation. These models, along with the production capabilities spectrum shown in Table 3, provide a framework for assessing production capabilities which also identifies the critical challenge as firms seek to move to more advanced performance standards (column 3 of Table 1). And it does so with concepts and assessment tools that make sense of the complexity of production to those involved in work.

Regional technology management capabilities foster regional growth dynamics. Technological diversification and networking are critical elements to the regional growth process, which can be described as an ongoing process of technological differentiation and integration. The process of design decentralisation and diffusion within and across firms is critical to both processes and the heart of the technology diffusion process, diffusion not only of technology but of new principles of production and organisation.[95] But unless firms have technology management capabilities the growth process will be stunted. And technology management capabilities are refined as enterprises move up the production capabilities spectrum.

The implications for an industrial policy of technology management are profound. The first, already mentioned, is the availability of the worldwide technology pool as a cheap resource *for firms with technology management capabilities*. The challenge for industrial policy is to

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[94] *Technology, too often, is conceptualised simply as a commodity and subject to the laws of supply and demand. Technology is a commodity, but it is also a capability. As a capability it cannot be bought and sold in the marketplace.*

[95] *This suggests why mission-driven business and production modernisation agencies that teach and diffuse participatory management practices such as kaizen, small group activity, cellular manufacturing, and total quality management have been central to the development and diffusion of technology management in rapidly growing regions.*

foster the development of the principles of production and organisation that form the platform for technology management in enterprises. This is a key to developing the internal technology/market dynamics of business enterprises and here followers have a huge potential advantage for fostering growth.

Unfortunately, the relationships between production principles and technology management are highly obscure, even to the pioneers. Over time, the advances in production capabilities became embodied in production practices and taken for granted. Today, however, these linkages are matters of historical record. Properly understood, they offer powerful growth levers at the enterprise and governmental levels.

A second implication is that the history of the evolution of models of technology management is also a high growth roadmap for technology followers. A history of changes in industrial leadership can be presented in terms of transitions to new models of technology management (a sequence of 'new competitions'). Regions with a critical mass of firms that were pioneers in the emergence of new models enjoy jumps in productivity and growth. The implied policy roadmap is of a terrain that alternates between hills representing the transition to new principles of production and organisation associated with higher levels of technology management, and plateaux where the new principles and capabilities are diffused across firms and industries. The speed of the vehicle, representing the rate of growth, inevitably slows for the transitions but, if the hills are climbed and the new principles established, the vehicle can again enjoy a long spell of steady speed (industrial growth) before a new hill is eventually encountered.

At each point along the way, growth for the technology followers occurs for as long as the ratio between wages and production capabilities is low compared to other countries. But the process of growth will advance wages until following nations make the transition to a new level of production capabilities and, enjoying a lower ratio between wages and production capabilities, undersell the market leaders.[96] Having achieved a new, higher level of production capabilities, a region or country enjoys growth as the new practices and technologies are diffused to old and new products by old and new firms. However, in the process, wages rise and opportunities for further diffusion diminish and growth becomes threatened as imitating

96 *Nakame Akumatsu (1962), a Japanese proponent of a unique theory of industrial development, described a process common to development literature but added an interesting twist. Countries would move from imports to import substitution to exports as they learned from foreign technologies. He described the process in terms of three waves of flying geese for each product. Imports would be represented by the first gaggle of geese in flying formation: increase, peak and fall off; production the second gaggle: increase peak and decline; and exports the third gaggle, again representing an inverted V pattern. He described these patterns as occurring first in 'crude' products and later in 'refined' products; in final goods and later capital goods. Where a country is at any point in time is determined by the balance of forces between the level of development and wage rates. Higher development leads to higher wages and a loss in exports of easier to produce goods. The idea of a production capabilities spectrum combines the principles of production and organisation described above with Akumatsu's notion of sectoral transitions. The production capabilities spectrum suggests criteria for locating a country in the international production order and for identifying the challenges at any point in time.*

regions and nations in turn develop the requisite production capabilities to move into the same markets but with lower wages.

To sustain growth, enterprises in such regions must be making the transition up to the next level of production capabilities. Once a critical mass make the transition, a new range of opportunities opens up as the region or nation becomes competitive in more technically and organisationally advanced activities and products. Growth reasserts itself as the opportunities are taken up until, once again, the ratio of the wage rate to the respective production capabilities rises above that of competitors. If a region or country successfully makes the transitions along the production capabilities spectrum then growth rates will be high and sustained.[97]

***Technology Transitions***

While new technologies are highly uncertain, technological trajectories have a logical progression.[98] Figure 9 illustrates both the change and the continuity dimensions of technological change. It shows major transitions ushered in by the introduction and integration of new technological domains into production systems. One feature is constant: a sustained reduction in critical size cuts across technology transitions. As technologists and scientists drive down the size of critical devices, new opportunities for technological change, new product development, new firm and new industry creation emerge.

The enduring evolution of precision machining toward ever smaller critical size illustrates a technology trajectory that will continue. As such, it can be a powerful industrial policy lever even in the most technologically advanced companies and regions.

Moore's Law is an application of the principle of decreasing device size in the age of microelectronics. But Moore's 'Law' is as much an industrial policy and business strategy as it is a scientific law. Intel, with the help of Sematech, played a role in turning Moore's Law into industrial reality. The predictability of the principle was used to great effect in government policies in the United States to resurrect the semiconductor industry.

97 *The dynamic process described starts with production capabilities and moves to higher rates of investment, greater learning-by-doing, greater competitiveness and sustained high growth. Savings follows from high profits. In this story, high growth generates savings; the conventional view attributes high growth to high savings but does not satisfactorily explain the sudden surges in savings. The production capabilities perspective starts with the firm and thereby focuses explanation on organisational capabilities and competitiveness; the conventional view begins with the consumption and savings choice of individuals as the determinant of growth. Empirical evidence supports the production-oriented perspective (Singh, 1995).*

98 *Kline (1985, 1991) argues that technological advance is often independent of, or at least precedes, scientific advance.*

Sematech was formed in 1987 to improve chip-manufacturing capability in US. Gordon Moore (1996: 172-3) describes its purpose:

> its founders organised a series of industry wide workshops to identify the technological advances required for U.S. semiconductor and supplier industries to catch up with Japanese industries. The outcome, in March 1988, was a timeline and the specifications for a sequence of technological generations that would lead to parity by 1994—a 'road map for semiconductor technology'. The timeline specifications required the demonstration of a 0.8 micron technology in SEMATECH's new wafer facility in 1989, with further advances to 0.5 micron technology in 1990, 0.35 micron technology in 1992, and 0.25 micron technology in 1994.

The Semiconductor Industry Association, founded in the 1970s, coordinated the activities of the Semiconductor Research Consortium (established to organise and focus university research, see Moore, 1996: 170) and SEMATECH. These agencies 'provided a road map for 15 years, pointing out key technology needs and the times at which those technologies would be required to keep the semiconductor industry on the historic productivity curve of a 30% reduction in cost per function per year' (*ibid*.: 173).

The predictability of technological change can be used to great effect by partnerships between entrepreneurial firms and government research programmes. It also illustrates the potential role networked groups of firms can play as collective entrepreneurs in shaping technological and industrial change. This example is played out everyday in every industry. Industrial policy has considerable potential to shape the technological trajectory of a region's enterprises by coordinating research activities.

### *Skill Formation*

Exploring the links between technology development and growth focuses attention on the most important contribution that policy-makers can make to rapid growth: human capital development planning for skill formation. Making the transition to more advanced models of technology management or into more precise technology domains will be blocked without the requisite skill base. The Capability Triad implies that each transition involves newly instituted processes in three mutually interactive domains: business model, production capabilities, and skill formation.

The application of new principles of production (and technologies) involves investment in counterpart engineering methodologies if technology is to be diffused and growth is to ensue. For example, applying the principle of interchangeability involves product engineering, just as applying the principle of flow means knowledge of process engineering. Leaders in the development of the new principles are also leaders in the development and diffusion of methods for educating the counterpart skills. Innovation does not depend upon a large skill base, but innovation-induced industrial growth does.

A region that can institute skill formation processes in anticipation of technology transitions has a competitive advantage over regions that lack such a capability.[99] Furthermore, realisation of investment in R&D often depends upon mid-level skill formation. Otherwise, the growth potential of research investment will be lost. Often, the critical factor is mid-level skills. This has been the case in the transition from electronic, circuit switched networks to ones based on optical, packet switched technology. In the words of a Lucent executive:

> Success in the Optical Networking marketplace is dependent upon rapid introduction of new technology. Reduction of the interval from research through commercial product is an imperative. If our workforce is not equipped with the necessary skill level to manufacture advanced products, production capability will not adequately support the volume levels needed to meet customer demand. If this occurs, profitable gain from our research investment will be lost.

In the case of optical networking equipment, it is estimated that a single graduate engineer can support five or six associate engineers. Combined with a *kaizen* or high-performance-work-system capability in operations, these combined skills can compress the times for new product introduction and production processes.

Regions that fail to integrate skill formation and technology change will risk undermining the skill base required to sustain production of once successful industries. Investment in mid-level skills is important for income distribution purposes, as well. The link between income distribution and technological change has been examined for decades. The research represents a 'venerable and fruitful tradition extending back to Paul Douglas (1926) and Jan Tinbergen (1975) of viewing the evolution of the wage structure . . . as depending on a race between technological developments and educational advance' (Katz, 1999: 1). When technological change is low-skill labour-saving, it means that the only way that technology-driven growth in productivity can be shared is through advances in education at the lower levels.

**Outline of the Path Forward: Ten Proposals**

We conclude with a brief summary of ten proposals to guide industrial policy in Northern Ireland. The proposals move from an emphasis on business model to capability development to skill formation, the three elements of the Capability Triad.

*1. Apply the principle of systems integration*

The Capability Triad, the key to transformational growth, requires the integration of change programmes in business model, production capabilities, and skill formation. At present, industrial policy agencies address each of the three separately. The critical inter-relationships

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[99] *Lipsey makes the point that skill formation can be turned into a basis for comparative advantage by public policy. He gives the example of Bismarck's education reforms and states: 'Many observers credit the German trade schools, that educate the majority of German youths who do not go on to higher academic education with providing the German comparative advantage in high quality standard consumer goods' (1993: 24-5).*

between, for example, capability development and skill formation are obscured. Fragmentation undermines the effectiveness of each agency. Consequently, the inter-relationships fall outside the purview of each specialist departments; yet it is precisely the processes of mutual adjustment that underlie the growth process. By reorganising industrial policy according to the principle of systems integration, the goals of capability development and skill formation, prerequisites to rapid growth, can become the focus of industrial policy activities, and the activities of the separate agencies can become mutually reinforcing.

Manpower planning for information technology (including the integration of hardware and software) is an example.[100] Northern Ireland has large university level programmes with enormous student participation in related disciplines. At the same time, virtually every firm in Northern Ireland needs improvement in information technology capabilities. Advances in IT can stimulate design, product development, and networking capabilities.

Energy efficiency is another example. The capabilities and innovation approach to high energy costs is illustrated in Appendix 2. It shows that the means of reducing energy costs is less marginal adjustment in existing processes and more the redefinition of processes with designed-in energy efficiency. Driving down energy requirements by an order of magnitude is a realistic goal for most manufacturing enterprises; implementing high performance work systems is a means of institutionalising the process.

Each is an example of designing industrial policy activities according to the principle of systems integration. It means government employees can become practitioners as well as advisors in organisational change. This is consistent with the leadership dictum of ‘walk the talk’.

*2. Concentrate on entrepreneurial firms*

Entrepreneurial firms can be characterised in terms of a technology-capability and market-opportunity dynamic that drives regional growth. Entrepreneurial firms are market creating because of their technological capabilities. The drive to advance their technological capabilities is simultaneously a market targeting, market refining, and ultimately market creating process. Because of their unique knowledge of product development possibilities, entrepreneurial firms can anticipate consumer demand. This anticipation reverberates back on product definition and capability development. This, in turn, triggers a new iteration of the technology/market dynamic.

The entrepreneurial firm advances a region’s technological capabilities in pursuit of market opportunities. Many will fail, but in the process the region’s capabilities and skill base are advanced and new growth potential is created. Emerging firms benefiting from experiences and skills gained in previous entrepreneurial efforts may well reap the rewards. The region gains in the process.

*3. Diffuse high performance work organisation*

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[100] *Like electrification in the early decades of the last century, digitisation is a general-purpose technology that is also a catalyst for redefining the production model to take advantage of the new technology.*

Firms organised according to the old business model are stuck at low levels in the production capabilities spectrum (PCS) (see Table 3).[101] Those that seek to advance up the PCS will be systematically inclined to develop a HPWS. In fact, the extent to which a firm has made the transition to a HPWS is one measure of entrepreneurial capability. Teamwork in a HPWS includes the integration of design and manufacturing, a key stage in advancing a company's new product development capability. While all firms pay lip service to customer needs, responsiveness to market opportunity depends upon rapid new product development capability.

The pervasive diffusion of the new model of work organisation was critical to the resurgence of the American economy in the 1990s. The proportion of employees in firms that made some use of self-managed work teams increased from 28% in 1987 to 68% in 1995 (Appelbaum et al. 2000). Fortunately, Northern Ireland has role models, but the proportion of firms that now use some form of self-managed work teams is probably below what it was in early 1980s America.[102]

Entrepreneurial firms can be fostered indirectly by advancing bottom-up managerial capabilities. Furthermore, gearing up these capabilities is, at the same time, fostering internal growth and creating a seedbed from which new firms emerge. Tables 1 to 3 indicate specific organisational capabilities and skill requirements.

For this reason, the HPWS and quality movements can be a catalyst for entrepreneurial firm formation both within existing enterprises and *via* new firm creation. The quality movement has developed a range of indicators of the productive capabilities of enterprises. A simplified, self-assessment measurement system should be developed to locate all industrial enterprises on a scale that reflects the level of production capabilities in Table 1.

The task of skill formation cannot be separated from production capability development. For example, skill formation in the form of self-directed work teams is critically important to the entrepreneurial firm. A great virtue of open-systems networking is the potential impact on disruptive innovation. Success at both the south and north poles (of Figure 5) depends on rapid new product development which, in turn, fosters innovation.

*4. Foster open networks*

Entrepreneurial firms are the drivers of regional growth dynamics. This is because entrepreneurial firms are the initiators of a range of regional growth dynamics that distinguish

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[101] *High performance work systems (or the less demanding management philosophy of total quality management), an integrative process approach prominent in world class manufacturing plants, is ignored in the Northern Ireland strategy documents. This is reflected in the functionally specialised makeup of the working party teams. Moreover, education institutions, as distinct from academic representatives, do not figure prominently in the working parties.*

[102] *Du Pont, Nortel, and Seagate's wafer fabrication plant are models. A number of Northern Ireland companies have begun the process (see footnote 72).*

high from low performance clusters.[103] These include techno-diversification, horizontal integration (or value networks), and industrial speciation (or new industry creation). Just as high performance work systems foster the decentralisation of design, inter-firm *networking capabilities* foster the diffusion of design. Such open-system networks are an infrastructure to enhance regional innovation.

A prerequisite to rapid new product development involving disruptive innovation is a business model of focus and network. In small regions like Northern Ireland, this will mean partnering with enterprises located in other regions.

Not only enterprises but also industrial policy should focus attention on networks for a purpose. In the case of industrial policy, the focus should be on networks to advance regional growth dynamics and technology management capabilities. The focus, again, is not on the firm but on the networks or inter-firm relationships which, in turn, foster the external/internal dynamic and thereby enhance the infrastructure for entrepreneurial firms and the organisational principle of increasing specialisation.

Networking is equally relevant for transformational growth. Companies at the south pole of Figure 5 must develop networking capabilities to trigger the external/internal dynamics of design-led clusters.[104] Companies at the west pole, in the case of Northern Ireland, also must pursue a focus and network strategy. This is because the region is too small to support large, vertically-integrated enterprises to base competitive advantage on throughput efficiency. But open-systems networking, here too, offers the benefits of regional innovation dynamics.

An industrial development strategy for Northern Ireland must be based on entrepreneurial firms and open-systems networking; the two reinforce one another. Open-systems networks are, to date, the only form of industrial organisation that supports regional competitive advantage based on PS 5 (see Table 1) and the principle of systems integration.[105] Before the development of PS 5 elsewhere, an industrial development strategy based on closed-system networks was a viable strategy. And before that, the business model of vertical integration and a market-coordinated supply system was viable.

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[103] *Three modes of inter-firm coordination: price, closed networks, and open-systems networks. Each mode affects the internal organisation of the enterprise differently.*

[104] *While advancing production capabilities is the basis for industrial diversification, it does not require movement of the composition of industrial output in the north and west directions as indicated by Figure 5. Instead, advances in technology management capabilities enabling rapid new product development can lead to growth and productivity advances in traditional, light-industry sectors such as furniture and footwear. But in every case, the business model of focus and network must be promulgated in line with the principle of increasing specialisation.*

[105] *Networking is also an attribute of the technology management capabilities associated with PS 4 and PS 5, requirements for competitiveness in complex production activities, associated with the west pole. Networking here is required to apply the principle of multi-product flow that, in turn, requires kanban type supply-chain management. Kanban based supply-chain management, as developed in Japan, depends on keiretsu, or closed-system networking.*

A great virtue of open-systems networking is the potential impact on disruptive innovation. Success at both the south and north poles of Figure 5 depends upon rapid new product development which, in turn, fosters innovation. Table 4 summarises the various sources of regional innovation associated with open-systems networks (see Chapter 2).

The small size of Northern Ireland dictates top priority to inter-regional networking as well. Fortunately, Northern Ireland has unique potential to network, as a region, with the fastest growing region in Europe, the RoI. Ireland has enjoyed regional growth dynamics that have reshaped and advanced the country's industrial base. But growth success creates pressures that, left unattended, undermine growth in the long run. Increased wages, land prices and various congestion costs all undermine rapid growth in the long run and create opportunities for nearby regions to absorb activities that spin out from core growth dynamics. As wages increase in the RoI, companies will be forced to increase productivity levels to match the higher wages; candidates for spinouts are greatest where they are unsuccessful. The opportunity is to supply the RoI with activities demanding lower levels of technology management capabilities that will also enable local companies to begin the developmental process of moving up the production capabilities spectrum.

Industrial policy should focus on networking, as distinct from firms, for another reason. Companies compete as members of networked groups of companies and the diffusion of new practices and principles across networked groups is critical to making the transition to more advanced technology management capabilities. An example is JIT production because it depends upon an inter-firm coordination of inputs and outputs which, in turn, puts pressure on suppliers to synchronise cycle times. This, in turn, creates pressures to move to cellular manufacturing and high performance work systems.

Investing in networks, instead of companies, means that the industrial policy-making agency is not dependent upon the successful introduction and implementation of new principles or practices in any single firm. Furthermore, the public investment is weighted in favour of generic and transferable capabilities.

*5. Develop technology management capabilities*

Rapid growth involves developing technology management capabilities to tap the world's pool of technology, a vast resource for regional growth. A tenet of the capabilities and innovation perspective is that social organisation must be in place in advance of or simultaneously with technology advances. Hence the stress on technology *management*.

The East Asian economies that have achieved high rates of growth have a critical mass of industrial enterprises with the capability to adopt, adapt, and diffuse technologies that originated in the most technologically advanced nations. Japan, South Korea, and Taiwan have developed the capability to develop new products and processes based on refining, fusing and advancing generic technologies. Together, these are the attributes of a national system of production and technology management.[106] Sustained high-growth rates depend upon making the transition along the technology management spectrum identified in Table 1 (column 7).

The policy implication is simple: technology management can be a powerful tool for achieving growth goals. Leaders in industrial development have developed new models of technology management and high growth followers have developed regional capabilities to manage technology. Technology management at the firm level is about developing the organisational capability to manage the technology/market dynamic; technology management at the regional level means fostering the virtuous circle of regional growth dynamics. Both involve policies concerning technology transfer, adoption, adaptation, development, combination, diffusion, and diversification.

This powerful policy tool for industrial policy-making is missing from the vision documents in Northern Ireland. Technology policy and technology research centres are aspects of Northern Ireland industrial policy but, as noted, the exogenous model of R&D and technology development is taken for granted. New, endogenous models of technology management and alternative concepts of innovation, such as the regional networking model, are not considered.

*6. Integrate technology management and skill formation*

Growth goals should be linked to inter-sectoral transitions toward activities and products demanding more production-complex and knowledge-intensive capabilities. Success can be measured by movement toward the west and east poles of Figure 5. This means developing and diffusing new product development and systems integration capabilities associated with PS 4 and PS 5 (Table 1).

Northern Ireland's education system is a source of potential competitive advantage for the transition to north pole activities. With the development of manpower programmes, business, government and tertiary education institutions can develop a shared vision and thereby coordinate efforts.

Perhaps the most important network for transformational growth and for success in the technology management capabilities (column 7 of Table 1) corresponding to both PS 4 and PS 5 activities and sectors is the inter-institution network which integrates the elements required for long-term manpower planning. Such a network involves moving from a fragmented organisational structure to an integrated enterprise, educational, and governmental skill-formation system.

In Northern Ireland, the major barrier to growth for technology management capabilities corresponding to PS 5 sectors and activities is not skilled labour, at least at the engineer, information technologist, and scientist levels. Rather, it is the integration of regional growth dynamics with skill formation processes. The latter means linking company technology visions, university curriculum developers, school teachers and resource planners (including teachers at

[106] *Slow growth followers, on the other hand, lack the capabilities to tap the world's pool of technologies. This is not surprising. Successful technology management itself requires the development of three distinct but interrelated capabilities: strategic, organisational, and production. Successful technology management, like the establishment of price for Alfred Marshall, depends upon both blades of a pair of scissors; supply must be matched by effective demand. While demand in price theory is mediated by income, demand in technology management is mediated by production capabilities.*

school, college, university, and company levels) into a single process. The RoI software manpower development programme is a model.

No programme is more important than manpower planning and skill formation. Northern Ireland has a research university and educational system that could facilitate the growth of technology management capabilities corresponding to both PS 4 and PS 5.[107] But even for firms that seek to develop competitive advantage in more traditional sectors and activities, the education system is likely to be a necessary partner to develop and sustain innovation (see Chapter 2).

Most regions of the world would be envious of Northern Irelands's university system, its science and engineering faculties, and the array of technology research and new product development centres. Every entrepreneurial firm in Northern Ireland has access to the skill base and R&D partnering capabilities the university system offers. Paradoxically, most of the research centres are highly under-utilised. Over the years, the university system has produced thousands of highly skilled professionals that work in and run entrepreneurial companies elsewhere. This is a strong asset that has yet to be converted into a regional capability to drive growth.

Technology parks linked to universities are particularly relevant to knowledge intensive industry. Kainos is a model of a successful university spin-off and QUBIS Ltd. has developed a methodology for establishing joint ventures between the university, its staff, and outside companies. The next step will probably be the development of technology parks.

*7. Partner with firms bringing inward investment to advance capabilities*

Inward investment should be assessed in terms of advances in the business model, production capabilities, and skill formation.[108] The purpose of foreign direct investment is not to increase employment and internal investment but to foster regional growth dynamics and transformation growth. Seagate and Nortel are examples (see above).

Information technology provides a particularly promising theme both for technology parks and inward investment in Northern Ireland. Software companies require little physical capital; the goal is not simply to create software companies but to diffuse software and hardware integration capabilities across industry.

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[107] *Japanese kaisha led the transition to technology management capabilities associated with PS 4, but the combination of closed networks and lack of industry/university partnering for dip-down innovation are barriers to the transition to the levels associated with PS 5 in Japan. For small regions, like Northern Ireland, the kaisha business model is not appropriate—its greatest capability is fast-cycle product development for high volume production. Northern Ireland industry does not have complementary capabilities in high volume production.*

[108] *In the late 1990s, nearly half of Irish Republic full-time manufacturing employment was in foreign-owned firms. These firms generated over 80% of manufacturing export revenues. Mary O'Sullivan reports that in 1996, net output per person engaged by US enterprises operating in Ireland was IR£177,000 compared to IR£34,600 for indigenous companies (see O'Sullivan forthcoming).*

*8. Integrate mission-driven diffusion agencies with industrial policy goals*

Governmental and non-governmental modernisation agencies can be ‘systems integrators’ for making a transition to higher skills, and powerful diffusers of new capabilities. A range of examples and models offer methodologies for success (see Best 1995). Northern Ireland has a large set of such agencies that, if unified by a capabilities developmental vision and led by a strategic agency, could focus their attention on fostering transformational growth.[109]

Industrial policy measures should target generic capabilities; firms take care of unique capabilities. Generic capabilities are regional assets or ‘social capital’. The microprocessor is the diffusion agent of the principle of systems integration that the machine tool was for the principle of interchangeability and electricity for the principle of flow (see Chapter 2). Specialist diffusion agencies can target specific capabilities and develop methodologies appropriate to a region.

The quality movement is a model. It is critical that the quality management approach be consistent with the development of the top-down/bottom-up (leadership/design) or technology/market dynamic of the entrepreneurial firm (see Chapter 2).

New product development is a second candidate for a specialised diffusion agency to drive across a wide range of firms. Firms without new product development capabilities are not organised to pull new generation technologies into production and thereby to pursue fast cycle-time competition. The goal for such agencies is to develop methodologies for systematically moving enterprises up the capabilities spectrum.

The Questor model (Chapter 3) is a model for connecting company change programmes with technical expertise in universities. Each of the entrepreneurial firms described above has developed links to university research centres. A proposal for increasing the region’s energy productivity by calling upon the Northern Ireland Centre for Energy Research and Technology is offered in Appendix 2.

[109] *The Northern Ireland Quality Centre is a prime example: it offers a methodology for organisational change for firms of all sizes and sectors. The Massachusetts Technology Collaborative (http:www.mtpc.org) has developed a set of indicators of innovation which could act as targets for improvement.*

*9. Link visible and invisible colleges*

Skill formation involves every level of education and every company, or it should. In Chapter 2 the role of learning and knowledge creation is explored in terms of the 'invisible college' of knowledge generation and diffusion. Production is about two outputs: goods and services, and information. A learning economy is one that develops means of capturing the information by-product and converting it into improved systems.

Skill formation also applies to tacit, or non-codifiable, knowledge built up by enterprises conducting experiments, formal and informal, over long periods of time. Tacit knowledge is often a critical ingredient in unique capability development and a source of unique competitive advantage.

Growth involves the expansion in all types of knowledge. The task of industrial policy, in part, is to account for all the types of knowledge that are required to achieve growth goals.

Northern Ireland, as noted, has a strong *potential* capability in knowledge-intensive activities based on its university system. Currently, university research centres are equipped to address the technological needs of companies and provide a means of increasing the technology skill base of Northern Ireland; but they are operating without a measurable effect on growth.

Regional technology colleges have played a key role in industrial growth in the RoI. Linking further education in technical skill development with research activities at university level could enhance the growth impact of both levels of education in Northern Ireland.

*10. Administer the research, technology development, and innovation infrastructure*

Knowledge-intensive industries depend upon support research in emerging technologies. In most cases, technological advance and development is a process of mutual adjustment between technology-driven firms, research-intensive universities, and government R&D funding. Sometimes the frontiers of technological research are pushed out by company-led agendas, at other times by university-led research agendas.

Industrial policy to support long-term growth in high-income regions involves government funding commitments in research and technology infrastructure.[110] Industrial innovation, as a set of regional growth dynamics (Figure 2), depends upon a responsive skill formation system. Developing governance capabilities for integrating university research, technology development, and industrial innovation has received little attention but it is the heartland of industrial policy in knowledge-intensive industries.

[110] *US industrial policy support for the development and application of the principles of interchangeability and systems integration was critical to establishing American industrial leadership in the middle decades of the nineteenth century and the latter decades of the twentieth century. The specific technologies could not have been forecast, but the generic technology trajectory was predictable. The latter involved the transition from mechanical to electrical to electronic to photonic and biotechnology domains. Government funding of science education was informed by these trends.*

The challenge is partly about making predictions about which technologies and industries will be the growth areas of the future. But equally it is about pushing the trajectories of generic technologies that will play a role in many future industries and foster a series of derivative future technologies. Biotechnology and ICT (information and communication technologies) are examples of technology domains that will have widespread industrial applications. Academic research in genome technology and photonics are investments in support technologies of the future, much like electronics was in earlier decades. All three, however, depend upon nano-technology production capabilities. Governments that invest in skill formation in these areas are not placing bets on the future, but investing in it.[111]

The challenge for industrial policy is to develop governance capabilities for fostering applied technological development to reinforce and foster the continuity of unique, regionally-based technological capabilities. Careful attention to the specific regional growth dynamics that extend a region's unique technological capabilities and leverage its technological heritage is critical to developing a region's competitive advantage and fostering industrial growth.

The technology infrastructure and skill formation process starts with maths and science teaching in the early years of education. The lack of penetration of technology in Northern Ireland's industry and declining enrolments in science and engineering courses at the tertiary levels can both be traced back to limited interest in science amongst young people and investment in preparing maths and science teachers. Industrial policy is, in part, about addressing bottlenecks in this process. Only government has the responsibility, the breadth of agencies, the time horizon, and the legitimacy to drive the institutional changes to synchronise industrial development and the skill formation process for knowledge-intensive industries.[112]

[111] *The National Development Plan of the Government of Ireland has recently integrated the Technology Foresight Ireland, a technology foresight exercise conducted by the Irish Council for Science, Technology and Innovation, into its industrial policy programme. The current annual budget of IR£20 million will be expanded to IR£1.9 billion over the seven-year life of the National Development Plan.*

[112] *The Northern Ireland Growth Council and the Industrial Research and Technology Unit established a steering committee to oversee six 'sector panels' to conduct technology foresight exercises. The 'sector*

*panels' were engineering, food and drink, textiles and apparel, life and health technologies, software, and networks & systems. Strategy 2010 involved forming 18 working group reports on various sectors. Forfas's Technology Foresight Ireland (1999) included the following panels: chemicals and pharmaceuticals, ICT, materials and manufacturing processes, health and life sciences, natural resources, energy, transport and logistics, construction and infrastructure. The panels identified a matrix of 'key strategic technologies'. The Irish Government is creating a Research Foundation to disburse IR£560 million over the seven-year life of the National Development Plan to support its industrial development strategy.*

# APPENDIX 1: CONSULTATIONS

| Firms, Government Agencies and Education Institutions | People Interviewed[113] |
|---|---|
| Bemac | Ms Brenda Beech |
| BIC Systems | Mr Brendan Monaghan |
| Belfast Institute of Further and Higher Education | Prof. Patrick Murphy |
| Biomedical and Environmental Sensor Technology | Dr Eric McAdams |
| Bombardier Aerospace | Ms Catherine McKeever |
| Boxmore | Mr David Dobbin |
| BT Software | Mr Seamus Doyle |
| DED | Mr Roy Gamble |
| Du Pont UK Ltd | Mr John Anderson |
| Economic and Social Research Institute | Dr John Bradley |
| Fraser of Allander Institute | Prof. Brian Ashcroft |
| Getty Connections | Mr Brian Getty |
| IDB | Mr Bruce Robinson |
| Institute of Advanced Microelectronics, QUB | Prof. J V McCanny |
| IRTU | Mr Greg McConnell |
| Kainos | Mr Frank Graham |
| LEDU | Mr Chris Buckland |
| Lisburn Government Training Centre | Mr Bill Jennett |
| Moy Park | Dr Ken Baird |
| Newry and Kilkeel Institute of Further and Higher Education | Mr Raymond Mullen |
| Norbrook Laboratories Ltd | Mr Martin Murdock |
| Nortel | Mr Alan Bowers |
| Northern Ireland Bio-Engineering Centre | Prof. James McLaughlin |
| Northern Ireland Centre for Energy Research | Prof. John T McMullan |
| Northern Ireland Economic Research Centre | Dr Nola Hewitt-Dundas |
| Northern Ireland Federation of Software Manufacturers | Mr William McClean |
| NI Knowledge Engineering and Dean of Informatics, UU | Prof. John G Hughes |
| Northern Ireland Semiconductor Research Centre | Prof. Harold S Gamble |
| NIBEC | Prof. Norman Black |
| Northern Ireland Growth Challenge | Mr Frank Hewitt |
| Northern Ireland Growth Challenge, Engineering Executive | Mr Alan Kilpatrick |
| Northern Ireland Quality Centre | Mr Bob Barbour |
| Northern Ireland Technology Centre | Prof. Eric Beatty |

[113] *Usually only a single individual is named for each company, institution, agency, or research centre visited. The names of colleagues are not listed.*

| | |
|---|---|
| Personnel, ex Shorts | Mr Brian Carlin |
| QUB | Prof. George Bain |
| College of Engineering, QUB | Prof. Brian Hogg |
| Development Office, QUB | Prof. John Fulton |
| QUBIS Ltd | Mr Edward Cartin |
| Questor Centre | Prof. Jim Swindall |
| Shorts | Mr George Cather |
| Randox Laboratories | Dr Peter Fitzgerald |
| School of Engineering, UU (Jordanstown) | Prof. N D Black |
| School of Management, UU (Jordanstown) | Prof. Richard Harrison |
| Electrical and Mechanical Engineering (Jordanstown) | Prof. J McC Anderson |
| Seagate Technology (Ireland) | Dr Kenneth Allen |
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| UU, Coleraine | Prof. Gerry Mc Kenna |
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# APPENDIX 2: ENERGY EFFICIENCY: APPLYING THE CAPABILITIES AND INNOVATION PERSPECTIVE

The Capabilities and Innovation Perspective calls for a radical rethink of how a range of industrial policy issues are conceptualised. The case of energy costs, an issue raised in both the NIGC (1995) and *Strategy 2010* (1999) vision documents, is an example.

Too often, manufacturers and industrial policy-makers see energy simply as a cost of production; the alternative is to see improvements in energy efficiency as a means of advancing manufacturing capabilities and product performance.[114] The question becomes, How can product, technology, process and production methods be redefined to improve energy efficiency? Examples of each follow.

**Product Innovation**

The Japanese use the term mechatronics to capture the fusion between mechanical and electronic technologies and have used it to great effect in improving manufacturing competitiveness across a range of industries (see Kodama, 1986). Stalk and Hout's description of the takeover of the 3-horsepower heat pump market by the Mitsubishi Electric Company illustrates how moving from mechanical manufacturing processes to mechatronics can promote both product innovation and efficiency in electric energy usage (1990: 110-114).[115] In nearly every year between 1976 and 1988, the Mitsubishi Electric Company introduced a process and/product innovation that enabled them dramatically to improve competitiveness and the energy efficiency ratio (EER). The EER increased from 7.4 BTU/Whr in 1976 to a range of 8-14 BTU/Whr (depending on the features) by 1988.

The list of innovations required to drive the improvement in the EER is extensive and illustrates the technology/market dynamic of the entrepreneurial firm: in 1980, Mitsubishi introduced integrated circuits to control the heat pump cycle; in 1981, microprocessors were added along with 'quick-connect' freon lines; in 1982, a high-efficiency, rotary compressor replaced the reciprocating compressor; in 1983, sensors and more computing power were added to enhance the electronic controls; in 1984, an inverter was introduced which enabled a dramatic increase in energy efficiency of electric appliances by allowing 'almost infinite control' over the speed of the electric motor; in 1985, shape metal alloys were added to control the air louvres; in 1986, optic sensors were introduced; in 1987, a remote personal controller was developed; in 1988, learning circuitry was added which enables the heat pump to adapt to the unique environment of each customer; and in 1989 electronic air purifier options were added. Not surprisingly, by 1990 Mitsubishi's 3-HP heat pump had taken over the American market and the former market leading American company had shifted from production of its own product to distribution of Mitsubishi heat pumps (Stalk and Hout 1990: 114).

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114 *Industrialists that realised the indirect, organisational advancing effects of unit electric drives gained far more than reduced costs of energy from the new power source. See the example of Ford in Chapter 2.*

115 *The Japanese use the term mechatronics to capture the fusion between mechanical and electronic technologies and have used it to great effect in improving manufacturing competitiveness across a range of industries (see Kodama, 1986).*

The example of the heat pump illustrates how a manufacturer can turn the challenge of high energy cost or the requirement for environmental improvement into an opportunity. It was made possible, however, because the company had developed the organisational capabilities of rapid new product development and short production cycle times. These organisational innovations were, in part, a response to a scarcity of resources, both material and energy.[116]

**Technology Substitution**

Steel making is the paradigm case in technology innovations that reduce energy intensity.
The use of scrap in electric arc furnace processes in the US has reduced energy consumption by 50% compared to traditional basic oxygen furnace processes. Continuous casting, by reducing cooling and reheating cycles, was another seminal innovation in improving energy productivity. But recently the development of thin-slab casting has opened steel's largest market—the sheets used in cars and containers—to the minimills. The energy cost is cut in half at casting/rolling stage between a minisheet plant and a highly efficient integrated plant (Schorsch, 1996: 47).

Steel is an example of how shifting technologies can yield dramatic improvements in energy efficiency. Cost-effective energy savings of 20-40% are identified for 5 major energy-intensive sectors by moving to state-of-the-art technologies, in a World Energy Council study titled *Energy Efficiency Improvement Utilising High Technology* (1995).

Manufacturers that integrate heat and energy generation commonly achieve dramatic advances in energy productivity. *Strategy 2010* states: 'CHP is one of the most efficient energy technologies for industry but, to date, only a few CHP plants have been installed'. The problem, again, is the lack of integration of the 'key principle' of creating a 'knowledge-based economy', technological change, and industrial policy with the result that recommendations are many and disconnected. The result is double signals, the death of effective policy-making. The intended target of the message has no way of setting priorities or knowing how to act.

**Process Innovation**

Why are the Japanese leaders in the introduction of state of the art technologies in energy efficiency? Part of the answer is that high energy costs fostered innovation (Porter and van der Linde, 1995). But price differences are only part of the story.

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[116] *Engineering capabilities are crucial to redesigning material transformation processes; at the same time, innovations in one application can be adapted by technically alert companies because of the limited number of technologically distinct processes. In fact, the number of ways by which electricity transforms materials is three: electromotive, electrothermal, and electrolytic. The electric motor, an electromotive phenomenon, accounts for roughly 75% of the electricity consumed in industry. Bulk processing industries (e.g. chemical, paper, primary metal, petroleum) involve electrothermal phenomena to produce heat which, in turn, facilitate a physical or chemical change. Chemical changes at the atomic level such as the production of chemical compounds like chlorine use electrolysis (examples from Gellings, 1994). Developing a regional capability for rapid diffusion of innovations and adaptations across a range of manufacturing enterprises is a feature of rapidly growing regions.*

While the Japanese have always focused more on minimising energy use than have American manufacturers, because of higher costs of energy, their unique approach to manufacturing management, and thereby energy reduction, has been an organisational emphasis on process or system. Improved energy efficiency ratios have been a by-product of the management philosophy that defines an organisation in terms of processes rather than functional departments. Process-oriented organisations set performance standards in terms of advancing flow across specialist activities; functionally departmentalised organisations evaluate performance in terms of department targets.
The distinguishing feature of the quality movement was designing quality into the process, not inspecting it in afterwards; the drive to minimise waste was associated with cellular manufacturing which is itself an application of process or flow analysis. The consequence was a holistic business organisation that dealt simultaneously with productivity *via* improved flow, quality improvement and energy efficiency. The management innovations that emerged in such organisations included TQM and continuous improvement that, in turn, fostered dynamics between process improvement and technical innovation. The example of Mitsubishi and the heat pump is about the application of mechatronics, but it occurred within an organisation that focused on process integration, the hallmark of the capabilities and innovation perspective.

This has important implications for a programme to improve energy efficiency. If the driver of such a programme is cost reduction, it is not likely to be successful. Much of manufacturing industry has electricity costs of no more than 2% or 3% of total costs. Eliminating such costs entirely may not improve competitiveness significantly. Furthermore, in many cases, companies that are not organised or seeking to organise in terms of process as distinct from functional departments and local optimisation will not have the organisational capability to address the single greatest source of energy efficiency improvement. But it also means that concern over energy efficiency can be a vehicle for addressing and advancing manufacturing competitiveness.

Just as in the case of the quality movement, which focused on the elimination of waste, the goal of improved energy efficiency *via* the process of energy reduction simultaneously contributes to productivity advance and cost reduction, but by greater amounts than simply subtracting the defects or diminished energy charges. Building the goals of improved quality and energy efficiency into the day-to-day activities of everyone in the organisation contributed to improved productivity by improving flow and creating targets for innovation.

The focus on process represents a breakthrough in thinking about energy efficiency in industry, just as designing quality into the process was central to the quality movement. In addition, process analysis is about applying the principle of flow, the fundamental principle of production that lies behind both Ford's single-product flow at the Highland Park plant and Toyota's multi-product flow or just-in-time system of production. Deming's (1982) 'theory of the system' is an application of process analysis to quality which revolutionised management thinking and practice. It provided a problem-solving management paradigm based on involvement of the workforce in improving flow via the elimination of defects.

The idea of process energy reduction is an application and extension of process waste reduction. Each represents a different form of waste: defects and energy. In the new management paradigm, increased competitiveness comes from achieving more comprehensive performance standards: increased productivity (measured in flow corollaries such as cycle time for production, new product development, design to manufacture, and technology diffusion), improved quality, and product performance. Tackling energy efficiency is part of the same production management system.

In sum, best practice manufacturing enterprises have developed the organisational capabilities to pursue a competitive strategy of rapid new product development, a management system informed by process flow analysis and driven by continuous improvement. This enables them to drive down the cycle time of the new product design to manufacture process. This capability, in turn, has revolutionised technology management in manufacturing: each time that a new product is introduced is also an opportunity to introduce new technologies, including electro-technologies.

**A Policy Proposal**

Thinking systematically about energy efficiency reveals the advantage of high performance work systems (HPWSs). In companies yet to develop HPWSs, the goal of continuous improvement in energy efficiency can serve as a catalyst for organisational change. Furthermore, advancing energy efficiency is helped by networking. Much can be learned from other companies. In addition, a mission-oriented agency can be a resource for promoting the regional diffusion of energy efficiency.

To achieve the goal of increasing the region's energy efficiency ratio, industrial policy-makers in Northern Ireland can call upon the capabilities of the Northern Ireland Centre for Energy Research and Technology (NICERT) at the University of Ulster. NICERT carries out research and techno-economic analysis, and provides industrial expertise in advanced fuel conversion and power generation systems (including their environmental impacts), in refrigeration and heat pumps, and in energy systems analysis and policy. NICERT has been involved in a range of large international projects which have involved leading companies as collaborators such as Mitsui Babcock, GEC-Alshom, Siemens, and ABB and, in the process, has built up an impressive academic and research staff. But NICERT is highly under-utilised in Northern Ireland. The task for industrial policy is to design industrial improvement programmes that stimulate the matching of resource capability with the unformulated need of companies to become oriented towards process improvement and technology management.

## GLOSSARY

**Adam Smith's fundamental principle of increasing specialisation** A process of increasing specialisation and division of labour creates wealth, for Smith. Specialisation involves the decomposition of the commodity into an ever-greater number of constituent activities; each activity, in turn, is targeted for a refinement in skills and technique. Every increase in the extent of the market increases the number of activities that are subject to 'new improvements of art'.

**batch production high inventory systems** A multi-product plant without flexible production methods. High changeover costs leads to long runs or large batch sizes and high work in process inventories. Often confused with mass production which has batch sizes of a single unit and virtually zero work in process inventories (see 'economic order quantity, Best, 1990: 151).

**benchmark analysis** The identification of performance gaps between the practices and processes of a plant or business and best practice. Involves studying best-practice or world-class standards.

**Big Business** A series of organisational innovations associated with the substitution of the visible hand of managerial hierarchy for the invisible hand of market coordination of economic activities (see Chandler, 1977; Best, 1990: 47-51).

**bottom-up entrepreneurial activities** Self-directed work teams can communicate directly with the customer and thereby decentralise the production capability and market opportunity dynamic.

**Canon production system** Used as an example of the extension of the principle of flow from driving down production cycle times to driving down new product development plus production cycle times (PS 4 in Table 1).

**capabilities and innovation perspective (CIP)** In contrast to the efficient resource allocation perspective, CIP focuses on resource creation defined in terms of production and organisational capabilities. This creates a framework for integrating technology and innovation into growth processes.

**Capability Triad** Breakthrough advances in productivity involve coordinated organisational changes in the business model, production capabilities and skill formation. Structural integration of production capability, business model, and engineering/technical skills (see Figure 1).

**cellular manufacturing methods** Involves co-locating the full range of machining activities required to make a part in a U-shaped configuration. It is a plant layout designed for multi-product, low inventory production. It complements self-directed work teams and requires multi-skilled workers.

**cluster growth dynamics** Combines the idea of cluster as networked group of firms and support institutions with growth dynamics internal to the firm as shown in Figure 2.

**CNC machine tools** Stands for computer numerically controlled machine tools. Computer controls, rather than the traditional skills of the machinist, guide the machining.

**concurrent engineering** The product and the production process are designed together.

**design modularisation** The design of sub-systems is independent of the system but, at the same time, enhances the flexibility of the overall system. An independently designed machine, for example, in a multi-machine production line that can communicate in the same instruction language as the other machines in the line.

**design/manufacturing cycle time** The time it takes to convert a new product design into a scaled-up plant capable of producing at competitive cost and quality standards.

**dip-down innovation** As opposed to the science-push model of innovation, the idea is that companies seek to 'dip-down' for basic research needs. They seek partnerships with research laboratories to address technological challenges that arise as they advance their core technological capabilities.

**disruptive innovation** In contrast to incremental innovation, a disruptive innovation changes the technology and the product architecture.

**dynamic dialectic model** A term used by Andrew Grove of Intel to describe a business model organised to combine recurrent phases of bottom-up experimentation and top-down direction.

**entrepreneurial firm** The growth driver in the capabilities and innovation perspective. 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).

**externally integrated enterprises** Productive units coordinated with 'closed-system' inter-regional networks or value chains directed by global enterprises.

**fractionated electric power** With the invention of electricity it became possible to decentralise the source of power within a plant. This meant that machines could be independently powered; power was said to be distributed or 'fractionated'.

**functionally departmentalised organisation** A business or plant organisational design in which all like activities are grouped by function and separated from other functional groups. Batch production methods tend to be organised by machining function such as milling, turning, grinding, etc.

**group technology** Plant organisation in which machines are laid out in separate cells each organised for a 'family' of parts or products involving similarity of sequential machining patterns.

**high-performance work systems (HPWSs)** These involve work settings in which workers experience greater autonomy over their job tasks and production methods, greater opportunity to upgrade their skills, participate in integrating design and manufacturing, and enjoy incentive pay schemes linked to system performance.

**horizontal integration or value networks** As distinguished from vertical integration or market co-ordination across companies, value networks involve partnering for complementary capabilities.

**industrial 'speciation'**. The emergence of new industry sub-sectors accompanying technological specialisation and diversification. Data storage systems, for example, have emerged as a new industrial sector following technological advances in the computer industry.

**industrial district model** Alfred Marshall noticed that firms in a similar industry tended to concentrate geographically (e.g. cutlery in Sheffield).

**IPO** A company's shares are offered, for the first time, on a stock market.

**interchangeability** The production of complete machines or mechanisms with methods by which the corresponding parts are so nearly alike that they fit any of the machines or mechanisms. It involves breaking down parts into their simplest activities and designing specialist machines for each activity. Distinguished from craft methods in which a craftsman makes each part and hand-fits it into the mechanism. (See Best, 1990: ch. 2.)

**interstice** Penrose's term for niche-market opportunities that have not yet been pursued (see also note 16)

**kaisha** Japanese variant of the entrepreneurial firm which decentralises design and builds continuous change into the operating units. This business model fostered the principle of multi-product flow and achieved cheaper, better, faster performance standards that established the new competition for high volume production. See PS 2-4 in Table 1.

**kaizen** Continuous improvement work system.

**Kaizen tiean** A system for eliciting commitment from every worker to contribute to on-going improvement (see note 83).

**kanban** The visual coordination of work activities within companies and along supply chains.

**keiretsu** Closed-system, long-term, inter-firm relations based on shared network norms.

**liquidity trap** No amount of increase in the money supply can stimulate demand and growth without a simultaneous improvement in expectations of future growth.

**Massachusetts' Route 128/495** A high tech region of the US, America's first high tech industrial district. Route 128 is a circular road around Boston; 495 is a circular road further removed from Boston.

**Moore's Law** Computer power doubles every 18 months along with the number of transistors on a single microprocessor chip. Size diminishes inversely.

**multi-product flow** The production of multiple products on the same production line or manufacturing cell without building inventory. This requires quick changeovers from product to product.

**nanotechnology** Nano- refers to size dimensions of a billionth of a metre, nanotechnology to building things on that scale.

**open-systems networking** Firms focus on core capabilities and network for complementary capabilities. This involves horizontal or multi-enterprise integration as distinct from vertical integration.
**PDCA** A methodology developed in Japan to diffuse total quality management.

**price-led competition** Firms do not organise themselves to introduce new products systematically. Instead, they compete by lower costs for a given product.

**principle of flow** Organising production activities to achieve throughput efficiency. It means equalising the cycle times for all parts required to assemble a product. Otherwise, bottlenecks will occur for longer cycle-time products and the longest cycle-time activity will determine the pace of production for the whole plant.

**process integration** A corollary to the principle of flow. Popularly referred to as lean production and re-engineering, it involves sequencing production activities according to the logic of the product not the machining function.

**product-led competition** Production is organised to be able to produce multiple products without declines in cost and quality standards and to be able to introduce new product designs without disrupting production.

**production capabilities** See production capabilities spectrum (Table 3). Examples:

| | |
|---|---|
| *precision machining* | based on the principle of interchangeability |
| *mass production* | based on the principle of flow (synchronisation) |
| *JIT or lean production* | based on the principle of multi-product flow and cellular manufacturing |
| *new product development* | based on an extension of the principle of flow from production to integration of design and production |
| *technology fusion* based | on the principle of systems integration |
| *incremental innovation* | (a.k.a. continuous improvement, *kaizen*, TQM) |

**production system** Regional economic success depends, in part, on the production system that has been developed in the region. See Table 1 and Figure 5.

**productivity growth** Economic growth can be broken down into productivity growth and labour supply growth. The second is growth generated by increases in the number of people in work. Productivity growth is the result of advances in production capabilities and is manifest in increases in output per hour worked. Productivity growth may or may not involve increases in capital equipment; it will virtually always involve capability development and complementary technological advance.

**regional growth dynamics model** A circular flow diagram encompassing the processes of techno-specialisation, techno-diversification, techno-integration, techno-standardisation, and industrial speciation (see Figure 2).

**regional production-system capability** Extends the continuity of technology capability from the firm to the region. Examples: precision-machining, mass production, flexible mass-production, design-led industrial districts (flexible-specialisation), complex-product systems. Anchored in specialised and unique application of one or more principles of production and organisation.

**science-push model of innovation** See note 23.

**scientific management** Work design based on presumption of a single best method that can be discovered by engineers and for which incentives can be devised to maximise work effort. Productivity is seen as dependent upon work time rather than material flow time. It fosters local optimisation. (See Best 1990: 55-58.)

**self-directed work team (SDWT)** As opposed to supervisor-centred work team, the SDWT internalises otherwise managerial functions and thereby economises on ‘indirect’ labour costs.

**six sigma quality system** A quality management methodology developed at Motorola and based on the goal of reducing defects to less than 34 per million chances. It has since been taken up by many leading US companies.

**speciation** A metaphor borrowed from botany to refer to innovation that emanates from new combinations of technologies that lead to new product applications and industrial classification categories. Furniture, for example, becomes interior design and furnishing.

**systems integration** The third fundamental principle of production and organisation. Operates at the technical and organisational levels. It means the organisational capability to redesign production to exploit design changes in sub-systems in ways that take advantage of interactive effects.

**Taylorist** *See* **scientific management**.

**technology domain** Examples: mechanical, electrical, electronic, photonic, genome, nanotechology. Anchored in scientific disciplines.

**technology (engineering) methodology** Technology domains, trajectories, and capabilities are converted to regional growth by complementary education processes that scale up the requisite skill base. The engineering curriculum is developed and diffused in partnership with technology/market dynamics of firms.

**technology management capability** The capability to develop and introduce new technologies, machines, materials, techniques and methods into production to improve performance. Technology management is not about *optimising* technological change but about *synchronising* the three elements of the Capability Triad around more advanced production principles to institute a process of sustained technological change. See the five models of production systems and technology management in Table 1.

**technology/market dynamic** An abbreviated version of Penrose's productive capability/market opportunity dynamic (see also note 22**).**

**technology (specific) capability** Continuity and change of specific technologies. Examples: turbine technology from waterpower to jet engine to power generation.

**technology trajectory** The never completed aspect of technology. Example: 'Moore's Law' (*q.v.)* predicts doubling in transistors per chip every 18 months. Special case of the Tendency of Increasing Precision.

**'third Italy'** Refers to the north central region of Italy that enjoys high per capita income but few large firms. The region enjoys competitive advantage in design-led and fashion industries.

**TQM** A management philosophy that involves everyone in the design as well as in the execution of work. Quality is designed into the work process rather than being inspected in after the defects have occurred.

**unit-drive electricity** Each machine as its own source of power.

**upas tree effect** 'The upas tree of Java (Antiaris Toxicaria), entering European legend through Erasmus Darwin, was believed to have the power to destroy other growths for a radius of fifteen miles. Here it is taken as a symbol of the heavy industries that so long dominated the economy and society of Glasgow' (Checkland, 1981: i).

**vertical integration** Involves the internalisation of production activities within a single company and coordination by the managerial hierarchy rather than by the market or by networks.

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