Cluster Dynamics in Theory and Practice: Singapore/Johor and Penang Electronics

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* This paper is part of a larger study of the Malaysian electronics industry carried out by the United Nations Industrial Development Organization and the Institute of Strategic and International Studies (ISIS) Malaysia for the Economic Planning Unit of the Prime Minister's Department, Malaysia, and sponsored by the United Nations Development Programme, Malaysia. Many of the observations on Penang are based on personal interviews conducted by the author in March 1997 and September 1998 arranged and accompanied by some combination of Lim Pao Li and Anna Ong of DCT Consultancy and Lim Kah Hooi of TEC Centre. Without the considerable respect all three enjoy in both private and public sectors it would have been impossible to arrange the interviews with virtually the Who's Who of Penang electronics, starting with the Chief Minister, Dr. Koh Tsu Koon.

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Malaysian Electronics: Growth with Limited Innovation

Malaysia's electronics industry is puzzling. It accounts for half of Malaysia's total exports and employs a quarter of the manufacturing labor force.[1] The annual rate of growth of manufacturing exports during 1970 to 1995 was over 25 percent per year and electronics accounts for two-thirds of manufacturing exports. Over the same 1970 to 1995 period, agriculture's share of exports dropped from nearly 75 percent to 13 percent and manufactures share increased from 11 percent to 80 percent.

Indeed, the specialization in electronics is much higher than in most OECD countries which gives Malaysia a strong foundation in the most innovative sectors in modern industry. The puzzle is why is Malaysia's per capita income so low given its apparent industrial structure? Even before the Asian crisis, Malaysian per capita income was roughly $4000, a sixth that of Singapore.

The competitive advantage of Malaysian electronics has shifted from low wage, labor-intensive manufacturing activities organized by foreign-based multinational companies (MNCs) to low cost, rapid ramp-up, high volume, increasingly automated manufacturing activities with special capabilities in assembly, testing, and packaging of semiconductors and hard disc drives (Best, 1997a). Nevertheless, the Malaysian electronics industry has reached a critical impasse: it is caught between lower-wage rivals that are imitating Malaysia's present production capabilities and higher-performance rivals with superior production and innovation capabilities. Sustained growth depends upon making a transition up the production capabilities spectrum. The question is how.

The poor value-added performance of Malaysian electronics is not lost on the government. Recognizing the problem, the Ministry of International Trade and Industry and the Economic Planning Unit of the Prime Minister's Office have developed a cluster-based strategy.

Second Industrial Master Plan: The Cluster-based Approach

The *Second Industrial Master Plan: 1996-2005* (IMP2), prepared by the Ministry of International Trade and Industry shares the assessment that sustained growth demands that the Malaysian electronics industry must make a transition "…to more automated operations involving high technology and knowledge-driven processes". It won't be simple: "…this internationally-linked group which has been driven by rapid changes in technology, product

[1] The electronics sector usually combines electronics and electrical products but electronics make up over 90% of the total output and employment (MITI, 1996, pp. 52-54).

development and innovation, changing consumer preferences and a short product life cycle, faces a number of challenges" (MITI, 1996, p. 63).

The Economic Planning Unit's *Seventh Malaysian Plan* marks subtle shift from reliance on foreign enterprises, as distinct from foreign direct investment, as the source of technology: "The primary source of technology will continue to be foreign enterprises…" (EPU, 1996, p. 2). The application of the cluster-based approach, however, emphatically marks a new direction.

> The IMP2…focuses on the cluster-based industrial development approach [to] improve on the existing industrial foundation of the manufacturing sector. **It will further strengthen industrial linkages both in terms of depth and breadth at all levels of the value chain."** (bold in the original, p. 30). The "cluster-based *Manufacturing* + + strategy… involves two basic thrusts: the move along the value chain to increase value-added at either end of the chain…[and] the shift of the entire value chain to a higher level thereby increasing value-added at every point along the value chain…(EPU, 1996, p. 31).

The *Seventh Malaysian Plan*, as well, stressed the role of government incentives to stimulate private sector involvement in the productivity-driven strategy. A series of governmental technology-policy related measures were introduced. The take-up rate, however, has been disappointingly low and science and technology indicators have not shown the desired advance (Rasiah, 1998). In short, the pace of adoption and diffusion of technology has stayed stubbornly low in Malaysian electronics. The easy answer to the question of why the limited take-up of such programs is that Malaysian enterprises lack the technology management capabilities required to make the transition to a productivity-driven strategy. This must change if the transition to productivity-driven growth is to take place.

The question is: Will the emphasis on cluster-based development foster the transition? The starting point of a cluster-based approach is to disaggregate the industry by region.

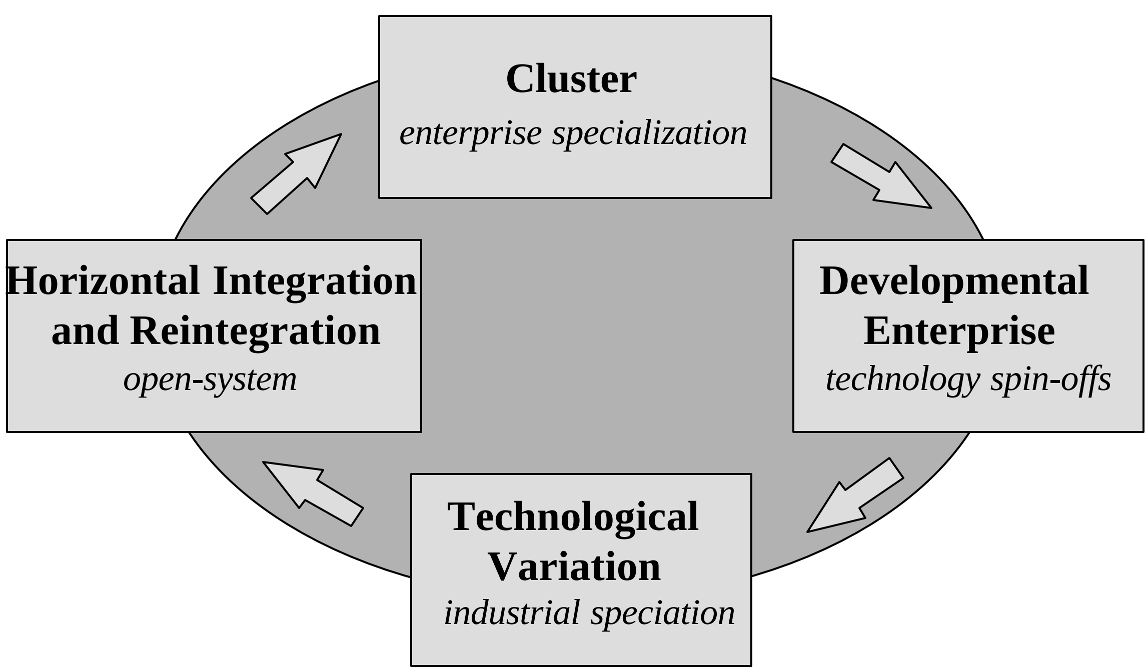
In fact, the Malaysian electronics industry is a composite of three micro regional clusters of roughly the same size in employment, namely, Penang, the Kelang Valley and Johor. Penang has the largest concentration with over 90,000 employed, followed by the Klang Valley with 85,000 and Johor with nearly 80,000 (MITI, 1996, p. 38). While all three districts are variants of the Singapore or third model, in that they are driven by MNCs, the linkages to corporate headquarters follow different patterns and, consequently, the regional dynamics within and across firms are different as well.

Evidence will be presented below that the electronics industry in Penang has indeed "developed the resemblance of an industrial cluster" but for the resemblance to be converted into a driver of the productivity-driven strategy the production and organizational capabilities of industrial enterprises must be upgraded and the skill formation processes must be substantially upgraded. What types of initiatives can foster advances in the technology management capabilities of enterprises? We take as a premise the idea that successful industrial policy must be anchored in an understanding of the forces that drive industry. The technology management perspective offers an understanding of these forces. But what are the links between clusters and technology management? Between clusters and productivity-driven growth? We address these questions from theoretical and practical viewpoints. In the next section a model of cluster dynamics is presented. In the following section the model is applied to Singapore. Application of the model to Singapore is at the same time an application to Johor as the two regions are integrated into a single electronics cluster. The success of Singapore suggest a criteria for assessing the situation of other clusters. Armed with both the theory and the application we turn to the case of the Penang electronics cluster.

A Model of Cluster Dynamics

Marshall's industrial district and Porter's cluster both introduce the organization of industry into the analysis of industrial growth. Growth involves some combination of an expanding population of firms and/or the rapidly growing firms. New and rapidly growing firms, however, do not grow in isolation but emerge from and develop within an industrial infrastructure constituted by a larger population of specialist enterprises.

Model of Cluster Dynamics



The box at the top of the figure titled Model of Cluster Dynamics signifies the type and extent of specialization within a regional population of firms. Greater specialization *within the cluster* is associated with the sources of productivity gain identified by Smith and Marshall. Porter's value-chain, likewise, suggests specialization in both supplying firms and feedback effects with specialized factors of production. *Greater specialization amongst firms within clusters is part of a process by which the cluster, as a whole, gains unique capabilities and regional competitive advantage.*

A dynamic cluster is one with a series of feedback effects which add to the technological diversity of a region. The driving force is the internal productivity dynamic of entrepreneurial firm. That dynamic, described above, is the outcome of an interaction between the expansion (the creation and release) of productive capabilities emanating from the successful completion of projects, on the one hand, and emerging productive opportunities identified and exploited by the entrepreneur or entrepreneurial team, on the other hand. This dynamic is a major source of productivity gain hidden in the technological residual or the term total factor productivity of macro growth theories. It is an organizational dynamic that does not rely on the expansion in the factors of production but in the development of productive capabilities and their interaction with emerging market opportunities.[2] The development of new products which reshape and increase the types of markets is one manifestation of the productivity dynamic.

The entrepreneurial, or Penrosian, firm is represented by the box at the right of the Cluster Dynamic figure. The entrepreneurial firm generates unique productive capabilities, increases technological diversity, creates new product development opportunities, and foster opportunities for other firms in the "interstices" (see below) all of which expand the potential specialization spectrum of an industrial district (represented by the top box).

However, the entrepreneurial firm not only enhances specialization by adding diversity to the regional population of firms; the pool of entrepreneurial firms is the source of a particular category of firms critical to economic development: "developmental firms". Developmental firms are those that play a pivotal role in the upgrading the technological capabilities and skill base of a regional cluster. Examples in the Technology Management Models appendix include the Springfield Armory which applied and developed the principle of interchangeability; Fairchild in Silicon Valley, and DEC along Route 128. Developmental firms are the source of new entrepreneurial firms.[3]

[2] Productive capabilities are attributes of individual firms. They are to be distinguished from production capabilities which are generic attributes defined in terms of principles of production. The latter makeup the production capabilities spectrum (see Table 2, Production Capabilities Spectrum).

[3] While the terms entrepreneurial firm and developmental firm are used interchangeably in the text a different connotation is suggested. The characteristics of both are fast growing, system integrators, employers of engineering/science professional, and organized for new product development. However, the idea of developmental firm is meant to suggest that the firm plays an important role in developing the skill base of the region. DEC, for example, as an employer of tens of thousands of technical staff and engineers was a major contributor to the skill formation of the Route 128 area, skills which were critical to sustaining innovation after DEC had gone into financial decline. A developmental firm is analogous to a franchise

While the entrepreneurial, and particularly the, developmental firm is the fundamental driver of economic progress; at the same time a firm's opportunity to specialize and develop its core competencies depends upon a "cluster dynamic" of mutually adjusting firms. In an organic, dynamic cluster, firms specialize in activities that require similar capabilities and partner with firms that specialize in complimentary but dissimilar activities.[4] The box at the left of the Figure signifies "horizontal integration", "open-systems", or networked groups of specialist enterprises.

The Penrosian productivity dynamic does not depend upon industrial districts or Porter-type clusters. It is equally associated with vertically integrated enterprises or the *keiretsu* model of industrial organization. However, what the sustained vitality of Silicon Valley and the resurgence of Route 128 illustrate is that the Penrosian enterprise combined with horizontal integration generates an additional dynamic, the "cluster dynamic" with a powerful effect on growth. This is the underlying force within the horizontal integration identified by both Saxenian (1994) and Grove (1996) as a major source of organizational advantage of Silicon Valley. It is the model of industrial organization most appropriate for product-led competition. It has long been denied in conventional economic theory which is built upon the assumption of a market or vertical integration, buy or make dichotomy.

The link between the boxes at the right and the bottom represents the dynamic between entrepreneurial firms and both "spin-offs" and new firms which expand regional technological diversity, replenishes the cluster dynamic, and sustain growth. An entrepreneurial firm generates new productive capabilities in the form of new technological possibilities only some of which it can pursue; the bottom box represents the emergence of new firms to exploit the new productive opportunities. In the process they create opportunities for specialization by other enterprises. These are taken up in greater number by "open-system" clusters which have greater potential for forming new combinations of resources (the left-hand box in the Figure), or new specialist enterprises some of which will become new entrepreneurial firms. In fact, the opportunity for and pace of sustainable innovation is closely linked to a diverse pool of technologies from which new possibilities and combinations can be developed.[5]

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athlete on a professional sports team; it is around such firms and individuals that regions and teams are built and thrive. Finally, a developmental firm can be government owned, as in the case of the Springfield Armory which was pivotal in the development and diffusion of the principle of interchangeability.

[4] George Richardson developed these ideas (1972).

[5] Ronald Kostoff has outlined several factors that are necessary to support successful and sustainable innovation (1994). These are: an advanced pool of knowledge; recognition of technical opportunity and need; an entrepreneur who champions the innovation; financial support; managerial expertise; and continuing innovation and development over many fields. What begins to emerge here is the idea that a vital component to sustainable regional development is enterprise accessibility to a pool of technical knowledge carefully fused with an accessible pool of organizational knowledge. To continually deepen the technical knowledge pool, for the education and training of workers and managers to keep pace with this expansive pool, and for the diffusion of knowledge over many technical fields to continue, collaborative behavior is essential.

Furthermore, spin-offs of a technical variety can lead to new industry sub-sectors which also will be facilitated by an industrial district of specialist firms; a new firm can specialize in developing an innovative idea and partner with other specialists for the requisite complementary activities. Horizontal integration is itself an enabler of technological diversity; it forms a diverse pool of collective knowledge or an "invisible college". Hence the collective learning noted by Saxenian.

In all of these ways horizontal integration speeds and amplifies the process by which new combinations of enterprises, or networks, are formed to exploit new opportunities.[6] Open-system clusters are continuously being revitalized by the process.

The mutual adjustment process anchored in the entrepreneurial firm is the basis of a bottom-up growth dynamic analogous to the self-assembly or self-organizing processes of systems theory. Such a process is constitutive of the design-intensive, fashion industries of the Third Italy. But the model of dynamic industrial districts or clusters has spread to electronics as well partly in response to the establishment of production and organizational capabilities that support product-led strategies. It is the organizational infrastructure to the decentralization and diffusion of design which characterizes Technology Management 5 (see Table 1; Best, 1998).

Singapore Cluster Dynamics and the Johor Region

The electronics industry of Southeast Asia began in Singapore following an investment mission to the United States in 1967 to establish Singapore as an offshore manufacturing platform (Chia Siow Yue, 1998, p. 12). In the same year Texas Instruments set up a semiconductor assembly plant to assemble and test simple integrated circuits for reexport to the United States. Following the American influx, MNCs from Europe and Japan followed. Reflecting national specialization, American MNCs tended to invest in electronic components (semiconductor and disk drive assembly) and industrial electronics (computer and telecommunications) and Japanese MNCs primarily in consumer electronics and electrical products.

Given the limited labor supply, the early focus on labor-intensive assembly activities increased wages and created pressures on profit margins. Increasingly, lower value-added manufacturing operation activities were relocated to low wage neighbor states. Thus high wages in Singapore meant the wholesale migration of factories into the adjoining region of Malaysia.[7] Singapore risked losing its manufacturing base and fears of industrial hollowing out were expressed.

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[6] The term horizontal integration is meant to suggest first, the decentralization and diffusion of design and second, collective learning. Examples of the first include relations between users and makers of machine tool companies in TM1 or design modularization and shared interface rules described in TM5. Examples of collective learning (or Marshall's industrial district) are open channels of communication across companies that are used not only to solve problems but to assess opportunities.

[7] In the early 1980s over 50% of the foreign direct investment by Singapore-based manufacturers went to Malaysia (Pang, 1995, p.117).

However, even though Johor was converted into an electronics region which employs nearly 80,000, the region's per capita income has not converged with that of Singapore. This has been so even though Malaysia's labor surplus was converted into a labor shortage with over 20 percent of the labor force composed of foreign labor. In 1997, wages were a quarter and property prices were less than a fifth those of Singapore (Sin-Ming Shaw, 1997, p. 64).

What appeared as de-industrialization was simply factory relocation. The MNCs did not relocate their whole operations to lower wage, labor surplus regions in the region. Instead they maintained non-labor intensive manufacturing and service related activities in Singapore and relocated merely the labor-intensive activities off-shore. The know-how and value-added from engineering intensive activities were not transferred even though the manufacturing operations take place in factories located in Malaysia (and in some cases conducted by Malaysian engineers working for MNCs with regional headquarters in Singapore).

The Singapore operations focused increasingly on more engineering intensive activities, including automation, product redesign, design for manufacture, and logistics functions associated with regional procurement including complementary business, logistics, procurement and financial services. For example, the division for product development projects focuses industrial design, upstream engineering and downstream engineering activities in Singapore and repetitive manufacturing primarily in Malaysia followed by Thailand, Indonesia and China (Tang, 1996, p. 231). Much of the resulting manufacturing activities in the Johor region of Malaysia are third and fourth tier, unskilled, labor intensive operations in consumer electronics related industries.

The transformation did not stop with a re-division of activities within MNCs. Singapore's competitive advantage and business model are undergoing a transformation. Singapore's electronics industry was strategically converted from a labor-intensive manufacturing operations platform for vertically integrated MNCs to a horizontally integrated manufacturing services cluster with ever increasing development of manufacturing-complimentary service activities such as engineering-intensive product redesign and process automation and complementary business services associated with regional coordination, procurement, development, and integration activities.

Singapore electronics industry, from this perspective, has successfully negotiated two transitions: internal to MNCs from labor-intensive to automation and from automation to integrated manufacturing and from vertically integrated MNCs to a dynamic cluster. In the mid 1990s, the electronics industry remains Singapore's most important manufacturing industry, accounting for 36% of manufacturing value-added, 25% of the manufacturing workforce and contributing 12% of the island's gross domestic product (Pang Eng Fong, 1995, p. 122-3). The foreign equity share of Singapore's electronics industry was 88% in 1992. All of these numbers are similar for Malaysian electronics. But the similarities stop here.

The value-added and per capital income differentials between Singapore and Malaysian electronics are strikingly large. For comparison, Penang represents the most advanced of Malaysia's three electronics regions and has roughly 87,000 employed in electronics in contrast to 127,000 in Singapore. But Penang electronics generates under 4 billion ringgit (just over US $ 1 billion) to Singapore's S$ 13.20 billion (US $ 8 billion) which translates to US $ 12,000 in value-added per person in Penang versus US $ 63,000 in Singapore. This multiple of 5 is less than the multiple of per capita income between Singapore and Malaysia of over 6 in 1997 (US $26, 475 to US $4,320 (exchange rate of US$1=RM 2.81, EPU, 1998 and Chia, p. 1).

A huge gap between income levels in Johor and Singapore has persisted even though they are elements of a single integrated production system. Why? What can be learned from the Singapore experience about generating rapid growth? The technology management and the cluster dynamics model provide a number of clues. Each of the following characteristics exist in Singapore. At the same time they offer criteria to assess the present position of Malaysia's three electronics regions and to shape a vision for their transformation.

Entrepreneurial firms. A dynamic entrepreneurial base is critical for acquiring technologies and exploiting market opportunities. Singapore industrial policy recognized first, the crucial role of entrepreneurial firms and that entrepreneurial firms can be local, joint ventures and foreign subsidiaries; second, that indigenous entrepreneurial capability was insufficient; and third, that entrepreneurial firms are both learning firms and have voracious appetites for engineering capabilities.

The development strategy was based on synchronizing skill formation with the progression of firms along the production capability spectrum. The strategy was not based on leapfrogging technologies but on incremental advances in production capabilities which facilitate transitions across the technology management models. The strategy was not R&D or design-led but based on upgrading manufacturing capabilities in synch with the engineering and technical skill base.[8]

Engineering and technical skill formation. The role of skill formation deserves special attention. Siow Yue Chia, director of the Institute of Southeast Asia Studies in Singapore points out that

> …since the 1960s, the educational system has been continually restructured—with emphasis on technical and vocational education below tertiary level to provide a growing pool of skilled workers and technicians; and rapid expansion of engineering,

[8] Mike Hobday presents a case study of Wearnes Hollingsworth Group, a Singaporan owned, entrepreneurial firm. Wearnes began as a sub-contractor of connectors and progressed to OEM, ODM, and OBM in personal computers and added software and R&D capabilities to basic manufacturing skills in electromechanics and precision engineering. Hobday notes that: "In the early 1990s, Wearnes still saw its main technological strengths in high quality engineering applied to electromechanical and electronic interfacing tasks, in connector manufacture, chip packaging, plastic molding and electroplating, rather than software or R&D" (1995, p.1183).

> business and computer education at tertiary level. Forty percent of the graduates from polytechnics and universities are trained in engineering and technical areas. The proportion of an age cohort enrolled in polytechnics and universities is targeted to reach 60% by the year 2000. Formal education is supplemented by training in specialized industrial training institutes to produce qualified craftsmen and technicians. The establishment of the Skills Development Fund provides upgrading training for those already employed (1998, pp. 2-3).

Matching productive capabilities and productive opportunities. The heavy reliance on MNCs was a means of focusing on building manufacturing and technology management capabilities that matched with emerging market opportunities (productive opportunities in the terms of the cluster dynamics model). With the development of design capabilities primarily manufacturing firms (or subsidiaries) took a big step to becoming entrepreneurial firms. These firms are still some distance from having innovation capabilities, at least in the case of electronics. Breakthrough innovation is concentrated within electronics clusters particularly in Silicon Valley and Route 128.

Competitive advantage in manufacturing and services associated with low-cost, high quality production engineering. Singapore did not seek to enter into competition with regions that have competitive advantages in software or in software and hardware integration but build a competitive advantage in the delivery of low-cost, high quality production engineering services. This competitive advantage goes beyond manufacturing to "packaging and integration" capabilities which underpin Singapore's emergence as a regional headquarters for supplying manufacturing services. A cluster analysis captures the full extent of what manufacturing services means.

Singapore as a packager and integrator. The expression "packager and integrator" comes from Enright, Scott, and Dodwell (1997). It captures the idea that Hong Kong or, by extension, Singapore firms are not mere coordinators of regional activities but "instigators and initiators" of economic activity, match demand and supply on local, regional and global levels. Such firms (or networked groups of firms) embody a complex of activities which enable them to add value

> through their knowledge of source and destination markets, through their familiarity with production capabilities of literally thousands of factories scattered throughout Asia, through advanced capabilities in logistics, and through expertise in managing subcontractors. Rather than a 'middleman', the Hong Kong [substitute Singapore] firm becomes a complete business partner for the customer, coordinating and putting together, 'packaging and integrating' a range of activities often beyond the capabilities of the customer…
>
> They provide a complete headquarters for management, financing, technology, design, prototyping, quality control, marketing, and distribution service between dispersed assembly plants on the one hand, and retail buyers on the other (1997. p. 55).

The cluster that captures all of the firms involved in ‘packager and integrator’ activities breaks down any manufacturing/services dichotomy; more, it transcends the metaphor of value chain with that of value network. The idea of a value chain is derived from a linear, assembly line context; the idea of value network captures the idea of real-time coordination and design integration across activities.

The left-hand box in the cluster dynamic circular flow captures the capability of a region to quickly form value networks. The roles of both the auctioneer or the middle manager in equilibrium economics are replaced by the network integrator in the dynamics paradigm. The network integration capability operates at the cluster level much as systems integration capability operates at the enterprise level. In both cases each unit is flexible and design-responsive and the whole is subject to redesign to address new challenges. Whereas systems integration depends upon technical interface rules, network integration depends upon trusted social interactions. Proximity is important to both; thus the metropolitan advantage.

The extent and type of specialization in the top box of the cluster dynamic circular flow in a dynamic metropolitan cluster contains a whole range of service type activities. In the case of Singapore many of these are elements of a manufacturing-services cluster. Singapore can not be faulted for having ignored the role of “low technology” supplier firms to a flexible “high-technology” cluster. Singapore’s skill formation system has supplied a steady stream of skilled labor to maintain a regional small- and medium-sized enterprise (SME) supply base composed of machine tooling, metal working, plastic processing, die and mold making, instrument making, and related specialist inputs into manufacturing.

Growth and high value-added in Singapore come from the development of cluster dynamics involving mutually reinforcing entrepreneurial firms, developing unique capabilities, spin-offs and start ups that are facilitated by skill formation and infrastructure, and a proliferation of specialist firms that can horizontally combine and recombine to rapidly carry out projects.

There is evidence that the Penang electronics industry is in the midst of a deeper transition in competitive advantage, the outlines of which are becoming clearer. The emerging competitive advantage is being driven by a range of “cluster dynamics” which themselves are anchored in the new business models that have been established in the leading electronics firms and industrial districts in which they operate.

Penang: Application of the Cluster Dynamics Model

Penang, one of thirteen states of Malaysia, was suffering in the late 1960s. Its historic trading role virtually disappeared with the political turmoil and national realignments and unemployment reached nearly 15% (Koh Tsu Koon, 1995, p. 2). In 1969 the state government established the Penang Development Corporation to “undertake and promote socio-economic development of

Penang" (PDC, 1994, p. 4). The PDC developed programs in industrialization, urbanization, urban renewal, tourism promotion and human resource development. In the next 25 years Penang has become a manufacturing center: manufacturing share in GDP increased from 13% to 50% (Koh Tsu Koon, 1995, p. 2-3).

But is the Penang electronics industry a dynamic cluster? If so, why has it not yielded a higher value-added performance. We turn to evidence that a cluster-based manufacturing system is emerging using the cluster dynamic model.

Specialization (micro-diversity)

While the Penang region began with a high concentrated specialization in first the assembly, followed by the packaging and testing of semiconductors, it built a high volume production capability in electronic components which spread to hard disk drives and, more recently, to myriad elements of the PC supply chain (DCT, 1998).[9] While many of these parts and components are elements in global production networks which are coordinated at the headquarters of MNCs and do not cross penetrate, recent years have witnessed a transition to a regional supply base with a growing degree of local horizontal integration. This has been accompanied by the emergence of a locally owned supplier base with increasing capabilities in technology management.

A number of studies attest to the superior performance of the Penang region amongst the three regional concentrations of electronics and electrical products in Malaysia. For example, in a study of technology absorption and diffusion amongst local supporting firms in the electronics industry, Suresh Narayanan provides evidence of a large gap between Penang and Klang Valley. He makes the following summary statement:

> In terms of our transfer framework, while all firms in both areas have passed the first stage of transfer (adoption), progress in the second stage of absorption is markedly different between supporting firms in Penang relative to those in Klang Valley. While more than half the firms in Penang have moved to the third and fourth steps of technology absorption (repair/modification skills), the majority of Klang Valley is still at the first stage of absorption. (1997, p. 22).

The higher level of technology diffusion in Penang is linked to a much higher proportion of local outsourcing by local firms. Narayanan finds that while local supporting firms in Penang sourced 46 percent of their inputs locally, the figure was under 13 percent for Klang Valley firms (1997, p. 23). In a detailed study of the linkages between seven electronics companies and nine

[9] DCT Consultancy Services, a wholly owned subsidiary of Penang Development Corporation has identified dozens of specialist parts and components along the production chain that are produced in Penang and the companies involved (DCT, 1998).

indigenous machine tool firms in Penang, Rasiah (1994) found that the latter fostered the growth of second and third tier suppliers. Narayanan summarizes Rasiah's findings (1997, p. 25):

> The first-tier vendors (those who had the first links with the electronics sector firms) have, in time, chosen to specialize in certain functions, and passed on some of their previous tasks to second-tier machine tool firms whom they now nurture. These second-tier firms have gone on to spawn their own third-tier subcontracting firms, giving them simply tasks likes parts fabrications which are no longer profitable for the former. In this way, not only has the number of machine tool firms increased but there has been a greater degree of specialization among them. These findings suggest a wider diffusion of technology through the agency of first-tier firms to smaller firms servicing them. The findings of this study have been corroborated by other observers as well (for example Lim, 1992 (sic); Teh, 1989).

The combination of a development of a regional concentration (high volume manufacturing in electronics components) and enterprise specialization is the building block for cluster dynamics. Nevertheless, the Malaysian electronics industry has a small base of SMEs by international comparison. Since the establishment of the first semiconductor plant in Penang in 1972, the industry has grown to over 850 companies. Taiwan electronics, which has an industry with roughly the same number of total employees, consists of over 3,300 firms (Dahlman, 1993, p. 257).

Entrepreneurial and Developmental Firms

The strategy of the PDC was to seek out the world's most entrepreneurial electronics firms, many of which fit what Intel's Andrew Grove (1996, p. 42) describes as the `new horizontal computer industry' (TM 5 in Table 1, a business model associated with horizontal integration, collective learning, and community institutions). Leading examples include Intel, Motorola, and Dell.

Penang electronics have advanced with the development of these companies. Lim (1991) describes in detail Intel's progressive moves from assembly to incremental change generating capabilities making it possible for headquarters to transfer technology to Penang and for the local plant to move to more complex higher value-added activities.

Intel's Penang design center, established in 1980, has 250 people and has progressed through three stages. First, they engaged in the design and redesign of mature products, for example the Intel 286 microprocessor, to improve optimization, yield rates, and robustness. At the same time they developed the capability to design chips which led, in 1992-4 to the second stage: product proliferation. During this period the first patent was awarded. Stage three has involved the Penang design center in original design for commodity or embedded applications and for PC central processing units (CPU) and chip sets. A second patent was awarded for intellectual property from their work in a new 8 bit CPU for embedded microprocessor applications, four other patents are pending. The mission of the design center is “to deliver compelling products faster than our competitors”.

Motorola is a similar story (see Ngoh, 1994). The R&D center which started with four engineers has nearly 120 today. Motorola Penang enjoys the design leadership in Asia for the CT2 cordless telephone. The Center does new product design, product-process interfacing and advanced manufacturing processing.

Dell’s Asian headquarters are in Penang. Dell is an industrial innovator; it is the leading example of the opportunity that the internet has created to build a mass customization business model. Dell’s “produce to order” business model combines the Toyota production system (cellular manufacturing, JIT, kanban, quick changeover, continuous improvement, self-directed work teams) with internet to integrate production and distribution into a single high-throughput process. Dell’s factory responds directly to the final customer; all intermediary distribution links are eliminated. The era of mass customization, in which each product was assembled to meet a specific customer’s specifications, has been promised for a decade but Dell’s organization plus the internet made it possible.

The implications are potentially as profound as other major technological innovations such as Ford’s redesign of factory architecture to use the arrival of fractional horsepower, unit drive electric motors to achieve, for the first time, synchronized or mass production (TM 2 in Table 1). To achieve the opportunities of the new model, Dell has developed ramp-up capabilities that are exception even for Penang; or perhaps Dell located its regional headquarters in Penang because of it competitive advantage in rapid scaling up of production. Dell achieved ISO 9002 certification within 8 months of commencing production, the legal minimum time-frame.

Furthermore, Dell pursues a simultaneous launch strategy. This means that the products made in Penang are first generation products, the same products made in Dell’s home office plants. This increases the challenge and opportunities for local suppliers to Dell to be on the cutting edge of new product and technological developments.

Rasiah (1995, chs. 6-7) identified cases of human capital deepening in local divisions of MNCs fostering technology transfer, particularly via skilled personnel moving to local firms. In Rasiah’s words:

> Intel, AMD, National Semiconductor…and Motorola Malaysia reported that former personnel…had started up new firms, and have offered substantial technical support to local firms (1998, p. 10).

This is not surprising as these companies are developmental firms in the United States and have long spin-off histories. National Semiconductor’s subsidiary plants in Penang, Dynacraft and Micro Components Technology, trained many of the region’s key personnel in precision engineering and metal working which now run successful local firms, including Rapid Synergy.

The development of supplier firms in metal working, machining and tooling, and plastics is critical to maintaining the competitive advantage of electronics in Penang. But, at the same time, the number of Malaysian owned entrepreneurial firms (firms with design and new product development capabilities) in electronics is limited. Outstanding examples in Penang are Eng Technology Holdings, UNICO Technology, and Globetronics. Each has been profiled by Lim Kah Hooi (1997).

Eng holds 8 percent market share in the worldwide disk drive actuator (a precision component) market; its customers are the who's who of the world disk drive and semi-conductor industry. Started in 1974 providing jigs and fixturing, it graduated to precision die sets and toolings supplied to the rapidly growing electronics industry. Today Eng consists of 4 main subsidiaries employing 350 people but it also is involved in a series of joint ventures in Penang, the Philippines, and Hong Kong in order to supply actuators on a JIT basis (Lim, 1997; Rajah, 1998b and 1999).

UNICO was established in 1992 by Intel Cooperative; the first product was the assembly of mother boards for Intel Penang (Lim, 1992; Lim 1997). Several Intel managers were seconded in the startup. Management has rapidly integrated upstream from a printed circuit board assembler to an OEM and ODM box product manufacturer through alliances with companies in Canada and Europe. In 1996, UNICO signed 4 joint venture agreements to manufacture PC workstations, Pentium notebook computers, modems, CD ROM drives, and digital enhanced cordless telephones. UNICO seeks to become a US $1 billion by 2002.

Globetronics, incorporated in 1990, was founded by two local techno-entrepreneurs who left Intel Penang to do contract manufacturing.[10] In the words of Lim (1997):

> At that time Intel was transferring new products at a fast pace from its corporate headquarters and Intel Penang was looking for a fast way of building up its capacity. As such Intel Penang decided to transfer out the older products together with the entire set of equipment to Globetronics.

Globetronics has formed joint ventures with Sumitomo Metal Electronics Devices of Japan to supply the semi-conductor industry with ceramic sub-strates, PCB assembly, leadframe plating and burn-in services. The companies goal is to become a turnkey contract manufacturer to the semiconductor industry.

Besides UNICO and Globetronics, the CEOs of Sanmatech, Rodel, and Molex, and Altera (the region's first design studio) came from Intel.[11] Ex-Intel manager also played key roles in the

[10] MTDC holds 30% of Globetronics shares.

[11] The information in this paragraph was supplied by Wong Siew Hai, Managing Director Intel Malaysia and Anna Ong, DCT Consultants in personal interviews.

development of Dell-Penang and AIC Semiconductor, which is locally owned). Two of Intel's design engineers left to help set up AMD's design center.

Motorola spin-offs that are supplying MNCs with world-class production performance include Sanda Plastics, LBSB, Eastrade and BCM Electronics. Micro Machining, a subsidiary of National Semiconductor, developed the skills of key people at Priority Plus (a local contract manufacturer) and Rapid Synergy (mold making and plastics products).

Intel, Motorola, and, potentially, Dell are exceptional in the commitment to local innovation and opportunities for driving cluster dynamics. They are developmental firms within the Penang context which are enhancing the skill base of the region (technical and managerial skills), a prerequisite to making the transition to integrated manufacturing associated with TM4 and TM 5 in Table 1. What is needed are dozens of locally owned entrepreneurial firms such as ENG's, UNICO's, and Globetronics.

Martin Bell and Mike Hobday conducted a survey of engineering, technical support, R&D, and recent innovations in 20 leading electronics companies in Malaysia. Their data show "substantial technical support for production and near-term technological needs" (1995, p. 47) and "A great deal of innovative activity is carried out, not only in changes to products and processes but also in the design and application of organizational changes" (p.47). They add that "In no cases was long-term or basic research (e.g. into new materials or advanced software engineering) undertaken locally…In a few cases some research related to product design and process developments was carried out by the largest firms" (p.47).

Technological Variation

Not surprisingly, the bottom box does not include examples of technological speciation (or the creation of new industrial sub-sectors) on a world scale. This is mainly because the electronics MNCs do 'product proliferation' rather than product design and new product development in Penang. But technological variation for the region is occurring.

The earlier development of precision engineering and machining are examples of new sub-sectors to the region that enhance the potential for technological diversity. For the future, the place to find potential for technology-related spin-offs is in the design capabilities of entrepreneurial firms.

The emergence of Altera, the first design studio, signals a new, critically important development in Penang's transition. The skills needed for "front-end" operations like chip design, systems integration, applications engineering are in short supply in Penang and what does exist is bottled up in the R&D facilities of a handful on MNCs. Intel's Design Center is a microcosm, internal to Intel, of the kinds of design capabilities that must become part of the wider cluster capabilities for Penang to make the transition to a more powerful cluster dynamics. The Penang Design

Center accounts for 3 phases in the development of design capabilities and tools across the following disciplines: mechanical engineering, electrical engineering, software engineering, media and communications, industrial design, and manufacturing.[12] Nineteen different software tools are involved; the Penang Design Center has at least one trainer for each tool.

The importance of local skill development can not be over emphasized. As one CEO put it, "If the changes outside the organization is happening faster than the changes inside, then the end is near" (Lim, 1997, p. 4). This is a recurrent theme.

Horizontal Integration and Reintegration

Companies such as Intel, Motorola, and HP have attracted world-class first-tier suppliers including contract manufacturers such as Solectron which, in turn, have filled in the PC supplier base making the region attractive to innovative PC assemblers such as Dell. Dell's strategy of combining the Toyota production system with the internet distribution channel has revolutionized the PC industry; a second feature of Dell's strategy, simultaneous product launches worldwide has created pressures in the Penang supplier base to operate at the frontier of production capabilities with first generation technologies.

Today Penang offers capabilities for state-of-the-art manufacturing and rapid ramp-up to high performance standards to market-led or design-led companies from anywhere in the world. Xircom, for example, is a fast growing telecoms company that "started the mobile computing revolution" with small, inexpensive, adapters that make it possible for notebook PC users to access their corporate networks. The Xircom adapter turns notebooks into desktop PCs in terms of connectivity to local area networks but without sacrificing the mobility of the notebook. Xircom's products are made in Penang only. The local managing director was chosen because of his networks in Penang. He was able to build a management team; assemble the operations personnel; identify, set-up and equip a plant; and get it running to high performance in a time span that may be the fastest in the world. Making the plant operational has involved ongoing interaction with Automated Technology, a process automation supplier literally across the street. Automated Technology personnel work inside Xircom's plant. This is what horizontal integration and collective learning are about.

Penang Cluster-dynamics: Strong Manufacturing; Weak Innovation

Penang's electronic industry is an emerging dynamic cluster with deficits in engineering skills, the extent and density of value networks, and entrepreneurial firms. At the same time Penang has manufacturing capabilities which could serve as a platform for making the transition to a cluster

[12] The Penang Design Center seeks to develop state-of-the-art design and manufacturing capabilities to transform product concepts into viable products. Advances in software, and modularization, have driven down the design cycle time. The design process has five phases: product definition, functional design, logic design, circuit design, and layout design.

dynamics that fostered industrial innovation. We look first at an optimistic reading of the transition potential based on Penang's considerable strengths.

Penang's strength: An electronics manufacturing platform

First, MNCs continue to locate in Penang because it offers them a powerful production platform. At present this production platform has much to offer that is not available anywhere else.

Second, MNCs, in order to stay competitive, have developed world class manufacturing capabilities in Penang at TM 2 levels (see Table 1), that is mass production including JIT and TQM systems with a number of examples of TM 3. These production practices enable participating companies to achieve world class performance standards in cost, quality, and time (not in time to market for new product development or innovation).

Third, American MNCs located in Penang tend to follow the Silicon Valley business model which stresses horizontal integration, collective learning, and community identity. Many features of Silicon Valley have been transplanted simply because it is built into the business model that informs their daily practices.

Fourth, the range of companies, services and division of labor in Penang constitute an "open system" industrial district in which virtually all of the activities required to rapidly set-up and ramp up high volume production on a JIT basis are virtually co-located.

Fifth, the Penang Development Corporation has been an exemplary intermediary organization in identifying and acting on collective needs and facilitating local enterprises to seize development opportunities created by the presence of MNCs. An outstanding example is the Penang Skills Development Centre (see Sidebar 3).

Sixth, the Penang electronics industry, as an industrial district constituted primarily by MNCs but with increasing local participation, is being driven by a set of dynamic forces that are built into product-based competition. These forces are creating new opportunities for advancing local capabilities if the right policies are developed.

Seventh, the "invisible college" of company skill formation is considerable in Penang. Many of the large American and Japanese companies invest sizable amounts, individually and collectively, in shop-floor skills. An audit of the quantity and quality of "invisible college" graduates from these programs would reveal a considerable regional asset or "social capital". These skills represents a sizable regional asset which have been accumulated over 25 years.

Eighth, the capability of rapid horizontal integration and reintegration to supply new products takes time to develop, is not easily imitated, and is problematic in high wage regions. It offers a competitive advantage platform upon which Penang can advance to higher technology management capabilities. Obvious steps are the transition to computer integrated manufacturing (CIM) for smaller volume, higher mix outputs. This has analogies, in terms of production and organizational capabilities, to the transition from TM2 to TM3 in Table 1. A second step is to move to a regional contract manufacturing capability that can also supply technology related services including design services, test engineering and equipment design, component qualification, failure analysis, value analysis/value engineering and prototyping (Kimmel, 1993, p. 156).

Penang's Challenge: Skills and Innovation Deficits

Penang is an electronics industry success story. But even though Penang has attracted many of the world's leading electronics companies and built an electronics cluster the level of value-added is small and declining.[13] The low total factor productivity is reflected in a low per capita income level relative to Singapore (about one-sixth). Why high growth and limited gains in per capita income? Much of the growth is linked to extensive accumulation or growth in labor and capital instead of gains in organizational capabilities. This, in turn, reflects a worrying reality: manufacturing capability is increasingly becoming like a commodity. With the build up in volume-production capabilities throughout East Asia, manufacturing plants are in excess supply. China's emerging capabilities in this area will only intensify the tendency of mass production manufacturing to be commodified.

In contrast, the "packaging and integration" activities, that link global demand with production, and "service and technology" enhanced manufacturing capabilities are relatively scarce and command higher returns.[14] The problem is that Penang lacks both "packaging and integration" capabilities relative to Singapore and technological innovation capabilities of Taiwan; instead, as a manufacturing center it is squeezed by regions with similar capabilities throughout East Asia. Worse, as a follower, Penang has little potential in wrestling away either the metropolitan advantage of the "packaging and integration" capabilities of Singapore or the skill formation of either Taiwan or Singapore in engineering-intensive manufacturing. Furthermore, although Penang does benefit from cluster dynamics in electronics the limited number of firms, technological diversity, start-ups and spin-offs suggest that it is a weak cluster dynamics without the high-powered injections from either research institutes, as in Taiwan, or complementary service-sector intensity, as in Singapore.

From this perspective, Penang's institutional, physical and skill formation infrastructures orchestrated by the Penang Development Corporation were highly successful in guiding the

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[13] Lim (1997) suggests a drop in electronics value-added from 31.4% in 1985 to 19.4% in 1994.

[14] Cary Kimmel, a Xerox executive, reports that a Xerox survey of suppliers in East Asia conducted over 1987-89 revealed the following:

> companies that provide S&T [factors related to service and technology] experienced a growth rate of over 400 percent during the three-year period compared with only 30 percent for the more traditional contract manufacturing companies. It is of more than passing interest that the greatest growth was experienced by those companies located in countries with well-defined national policies that encouraged the growth of S&T capabilities (1993, p.158).

transition to a high-volume manufacturing cluster. But a new transition is called for and will require an entirely different set of institutional and skill formation capabilities. Unfortunately, to date, a similar strategy or consensus has not been developed to begin to mobilize the resources.

The most crucial short-fall is in the skill formation required to foster entrepreneurial firms and industrial innovation. There are no short-cuts: innovation in electronics is engineering intensive. Penang's limited innovation related skills, given the considerable manufacturing capabilities, illustrates the limits of an electronics infrastructure that does not include strong skill formation capabilities in areas such as design engineering, computer science, systems analysis, and information technology generally.

The problem is understood in Penang. Koh Tsu Koon, the Chief Minister of Penang, indicates the numbers involved, if not the scale of investment in higher education required to address the challenge:

> It is estimated that there are now about 12,000 scientists and engineers with a Bachelor of Science degree or equivalent working in Penang. This works out to a ratio of 10,000 scientists and engineers per million population, which is lower than that of over 25,000 per million population in Singapore and Hong Kong. We must therefore aim to reach the ratio of 25,000 by year 2002…With Penang's population expected to reach 1.4 million people, we would need at least 35,000 scientists and engineers by then, which means that we must produce and recruit some 23,000 scientists and engineers within the next eight years, or about 3000 per year. This is a very tall order indeed. (1995, p. 12).

With a ratio of 10,000 scientists and engineers per million population, Penang more than quadruples the Malaysian national figure of 2,300 per million. This means that Penang will likely have to grow its own engineers and scientists. While individual firms can poach engineers from one another and can harvest the existing crop of students, the region as a whole must plant new seeds in the form of an expanding flow of students entering into engineering and information technology related programs.

Industry and state government has a history in Penang of responsive collaboration in skill formation at the technical skill level. Each year the PSDC offers courses to over 8000 students (see Sidebar 3). The collaboration has contributed to the targeting of curriculum and upgrading of shop-floor skills appropriate to high-volume manufacturing production.[15] Presently, the PSDC is moving into information technology with a series of pilot projects that, if scaled up, could make a big contribution to upgrading the IT capabilities of the manufacturing labor force. A Bangalore, India software training company has been contracted to teach computer programming skills.

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[15] Lim documents both the areas of strength and the missing areas (1997).

Why the lack of a similar program at the engineering education level? Faced with a skill shortage of manufacturing and technician skills, industry and state government created the Penang Skill Development Center to expand skills.

The main answer is that, the world over, even big companies do not have the time horizon to engage in skill formation investments for engineers or computer scientists. It was a matter of months between the time the concept of the PSDC was established in May 1989 and courses were underway; within months companies were enjoying the benefits of training programs.

The first reason, then is time scale: it takes not months but years for the training of engineers, and software engineers and developers. The second reason is that the qualifications for teachers is much higher. In the case of technician and manufacturing skills, companies themselves run related training programs and could quickly upgrade the quality of teaching staff.

Therefore, the bottleneck constraint in engineering skill formation is qualified teachers. It takes 4 years to increase the output of new engineers or scientists at the bachelor of science degree level even if the supply of qualified university entrants is available. To increase the flow by 3,000 per year means 12,000 students in a four year program and, with a student to teacher ratio of 15:1, 800 additional faculty with the appropriate engineering and science qualifications. This is a tall order indeed.

Given the shortage of engineers and scientists in Penang, finding over 800 quality faculty with the requisite capabilities and experience will be difficult. The major pool of candidates would likely be from within the MNC companies and Malaysians working overseas. To attract faculty will require considerable attention to quality of life issues. But it would also involve considerable attention to a curriculum appropriate to building on the strengths and strategic opportunities for Malaysian electronics.

The benefits from building up university education programs in engineering are not only in skill formation of engineers. The development of both the Route 128 and Silicon Valley electronics clusters involved the simultaneous development of university departments, research institutes and curricula, on the one hand, and rapidly growing entrepreneurial enterprises, on the other. This dynamic is the hot-house environment that has nurtured techno-entrepreneurs, important drivers of cluster dynamics.[16]

This captures the challenge of making transitions: without adequate graduates, new graduates can not be produced. Nevertheless they must be. This is the case in Penang. It will require the development of a plan in which companies, universities, regional and national government all make substantial contributions.

[16] The best Asian model for the development of techno-entrepreneurs is Taiwan.

There is another big reason to make the investment. Skills and schools are local, immobile resources. Graduates from regional colleges and technical schools around the world tend to remain in the region.

Meeting the "tall order" will require institution building which will, in turn, require a large commitment of government funding, local political leadership, and industry/education institution partnering to develop the skills required to make the transition. The range of incentives that attracted MNCs to Penang were successful but they are not appropriate for addressing the transition challenge. Incentives that mask economic fundamentals—incentives that if withdrawn, would not leave behind lasting economic activity in the region—must be avoided. Effective industrial policy is more about education policy and technology policy than about tax incentives.

Industrial Policy Implications

The capabilities and innovation paradigm

Industrial policy, explicitly or implicitly, is anchored in an economic growth paradigm. The growth challenge in Malaysian electronics is to bring about a transition in how regions (firms, governments, education institutions) invest and organize to facilitate cluster dynamics—the drivers of which are entrepreneurial enterprises. A clear vision of the challenge depends upon shifting from an industrial policy informed by a market-centered, labor and capital growth paradigm to a capabilities-centered, innovation and knowledge expansion paradigm.

An industrial policy geared to stimulating cluster dynamics must focus on knowledge creation, enterprise development, and industrial innovation. At present, industrial policy and technology policy measures are geared to stimulating foreign direct investment (FDI) as a source of capital accumulation instead of FDI as a handmaiden to the entrepreneurial firm (productive capability/productive opportunity) enterprise dynamic which stimulates enterprise diversity via spin-offs and start-ups and, in turn, new patterns of inter-firm networking. By industrial innovation we refer not simply to the number of scientists working in research laboratories, (exogenous innovation of the old growth paradigm) but to product and process improvement, new product development, design and technology management capabilities, new applications of production principles, technological diversification, and industrial speciation, or the emergence of new industrial sub-sectors.

The market-centered paradigm obscures the relationships and capabilities (production and organizational) in which industrial innovation and growth are embedded. The institutional starting point is the entrepreneurial firm. The idea of the entrepreneurial firm is that capabilities, as well as capital and labor, must be nurtured and developed. From this perspective production is seen as producing not only goods, but equally importantly, of stimulating and producing ideas. The challenge is to discover and integrate new ideas into the productive capability/productive opportunity dynamic. Ideas are raw material for the innovation process within both firms and clusters, by enhancing technological diversity and spawning new industrial sub-sectors. Ideas, finally, can come from anywhere: customers, shop-floor workers, suppliers, engineers, managers, competitors… In dynamic clusters, like Marshall's industrial district, ideas beget ideas.[17]

Firms do not compete alone in the market place but as members of networked groups of firms. Inter-firm cooperation in knowledge creation is central to dynamic (non-price) mutual adjustment processes that advance productive capabilities and enhance innovation. The task of industrial policy makers, in part, is to shape the form of competition and patterns of cooperation amongst firms within their domain; this means advancing the regional capability for experiments, innovation, and skill formation so that the cluster of firms, as distinct from individual enterprises, remains viable in the face of inevitable environmental change.

Competitive systems have both generic and unique aspects. They are generic in that they are consistent with underlying principles of production and organization but unique in that entrepreneurial firms and industrial districts build on productive assets that have combined and developed in unique patterns and thereby enjoy unique productive opportunities. The challenge to firms and clusters is to build on core capabilities to establish unique offerings that can not be easily imitated by other firms and clusters. This involves building product development strategies on the basis of technological bases for which firms have formal and tacit knowledge, and partnering relations unavailable to those without similar depth and breadth of experience and teamwork and density of partnering networks.

The capabilities/opportunities framework offers a criteria for distinguishing static from organic clusters which, in turn, makes industrial organization and industrial policy endogenous. Related issues of production capabilities including technology management are no longer exogenous to the economic growth perspective. The role of technology in economic development is much broader; for example, companies can pursue technological development by purchasing R&D equipment or by building technology management capabilities, rather than funding research laboratories.

Similarly, the focus on capabilities, combined with cluster dynamics, creates new possibilities for both understanding growth dynamics and strategic industrial policy. For example, industrial policy, too often, seeks to identify and fill "missing firms" or inputs in a value-chain. The cluster dynamic analysis focuses, instead, on organic links that emerge in the process of problem-solving by entrepreneurial firms. Singapore and Hong Kong have broad and dense networks which enable "packaging and integration" but these could not have been predicted. The task is to identify emerging networks and foster them.

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[17] For the entrepreneurial firm, short-run optimality may be long-run death. Since enterprise and cluster dynamics eventually force market transitions and redefinition, sustainability demands that firms must invest in search and experiments. These investments are costly in the short-run but critical to survival in the long-run.

As developed in Best (1998) the opportunities for industrial policy at any point in time depends upon the relation between productive capabilities and costs of production relative to other regions. This growth model is derived from the technology management framework illustrated in Table 1. As industrial regions develop, variation and uniqueness amongst enterprises proceed and unique regional capabilities emerge.

Fostering Cluster Dynamics: Entrepreneurial Firms and Development Agencies

The goal of industrial policy is to foster cluster dynamics. This can mean developing regional institutions which stimulate innovation and industrial growth by fostering dynamic, networking enterprises. MIT and Stanford University are paradigm examples of educational institutions that have fostered the development of organic clusters anchored in new technologies. Similarly, the Electronics Research and Service Organization (ERSO) in Taiwan has fostered the emergence of technology-based enterprises which, in turn, have stimulated cluster dynamics corresponding to the interactive principles of specialization, variation, and uniqueness.[18] In Japan and Korea, government agencies such as MITI have sponsored technology transfer programs, next generation R&D projects within a business model of the *kaisha* and *chaebol*.[19] In Singapore, the Economic Development Board has invested heavily in skill formation including scientists and engineers and in an infrastructure which give incentives for MNCs to transfer product design capabilities to Singapore (Magaziner and Patinkin, 1989; SISIR, 1992; Dolven, 1998; Best, 1997b).

Not surprisingly, technological followers have developed industrial policies to advance production capabilities and foster entrepreneurial firms. In all cases, intermediary, mission-driven agencies have been established either by government or intermediary organizations to administer programs that enable firms and whole clusters to make transitions along the production capabilities spectrum. These policies may involve a set of tax incentives and subsidies and the provision of infrastructure, but they also involve programs and agencies designed to advance production and organizational capabilities. Central to many are policies directed at the adoption, adaptation, and diffusion of technologies.

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[18] ERSO, a public agency founded in 1974, "..stands between the domestic electronics firms and the rest of the world for the purposes of facilitating the transfer and assimilation of advanced technologies" (Wade, 1990, p. 107). See Wade for a description of ERSO as a catalyst for the development of Taiwan's information technology industries, including the proliferation of design houses (1990, pp. 103-108). For a contrast between Taiwan and Singapore industrial policies and industrial organization see Dolven (1998).

[19] The kaisha and the chaebol can also be seen as examples of industrial policy to establish developmental firms which, in turn, become the drivers of technological advance; similarly, R&D spending by US governmental agencies has often gone to the development of firms which spawned new industries. A paradigm case would be the federal government's funding of BBN Corporation of Cambridge MA to create the ARPA Network, forerunner to the Internet.

High-tech clusters are particularly dependent upon skill formation agencies and activities. The definition and measurement of knowledge workers is inherently ambiguous. It involves formal and informal education and formal and job-oriented learning modes. We have noted the co-development of MIT and Route 128 and Stanford's college of engineering and Silicon Valley. Both regions have been prodigious producers of "knowledge workers". Both, however, represent a small proportion of the engineering degrees awarded each year. About 5000 engineering degrees are awarded each year by Massachusetts colleges and universities (MTC, 1997, p. 22; Massachusetts has a labor force of slightly over 3 million people).

An ongoing effort to measure information technology workers in Malaysia uses occupational categories from 1991 census data. Out of a total labor force of about 6 million, the study estimates the following occupational breakdowns: about 7800 persons (0.13% of the labor force) were in the categories of Systems Analysts or Computer Programmers and Statistical and Mathematical Technicians; about 6000 Electrical and Electronics Engineers, and about 28000 Electrical and Electronics Engineering Assistants and Related Technicians (UNDP, 1998, p. 43).

These number may be far off the mark. The numbers suggest that the flow of new engineers in Massachusetts represents a comparable figure to the stock of engineers in Malaysia. Nothing is more critical to developing an innovation economy than skill formation. Fortunately, a lot can be done in "invisible colleges" to upgrade skill formation levels as well as the visible colleges.

We turn next to informal and formal sources of skill formation and knowledge creation in Penang. The growth and sustainability of clusters depend upon two knowledge-related processes: the innovation process (this included technology management, development, and diffusion) and the skill formation process.

Invisible Colleges: Knowledge Transfer and MNCs

Ideas are the raw material for the innovation process; both are bound up with a skill formation infrastructure. Skill formation is a long-term process, including formal and informal sub-processes, embedded in partnering relationships across schools, firms, government, and the polity. Nurturing these relationships is as basic to the skill formation process as investing in the physical infrastructure is to supply chain management in the manufacturing process.

Many of the large American and Japanese companies invest continuously in shop-floor skills. In fact, the "invisible college" of company skill formation is considerable in Penang. An audit of the quantity and quality of "invisible college" graduates from these programs would reveal a considerable regional asset or "social capital" (Lim, 1998, offers a starting point for a skill survey). These skills represents a sizable regional asset which have been accumulated over 25 years.

The MNCs in Malaysia are representatives, or elements of, the national systems of innovation of their home base country. This means that each subsidiary organization within Malaysia is an element of a knowledge-increasing production system even though the idea creation potential of the subsidiary has not been developed or exploited within the Malaysian context. Realization of knowledge-creation potential depends upon a networked, organic relationships with other elements in the respective national systems of innovation. Nevertheless, much can be learned from the local representation of each national system and functionally equivalent "infrastructures" or networks of complementary institutions can be developed to better exploit the repressed knowledge-creation capabilities.

The MNCs with subsidiaries located in Penang often have world class programs and processes located in other regions which can be benchmarked and applied to Penang.
If fact, embryos of such programs and processes can often be found in the subsidiary. Three examples follow.

One example is small group activity (SGA) which constitutes the work organization of many Japanese companies. Hitachi, in Penang, uses the same continuous improvement, *kaizen* work system that made the company a world leader in a range of electronics sub-sectors. The operational performance of the Penang plant generates a high level of productivity at the shopfloor level *within the constraints of the innovation infrastructure*. Hitachi-Penang does not co-locate applied research and manufacturing operations and does not integrate, locally, applied and developmental research. Consequently, the productivity potential of the system is limited. At the same time, SGA is a prerequisite to making the transition from TM2 to TM3 (see Table 1) because it provides the flexibility and shopfloor problem-solving capability required for mixed-product flow. Hence it is a building block for higher levels of industrial innovation. It is also a model that, if diffused, would enhance the skill formation of the region.

Motorola's United States supplier development program, a second example, is often benchmarked by other companies. Key features of the program are industrial cooperation and networking with junior colleges to develop curriculum and to train the trainers.

BCM is a beneficiary of Motorola's supplier development program in Penang. A systematic 5 year technology transfer methodology has been developed with two complementary activities: manufacturing systems know how and engineering know how.

Manufacturing know-how transfer involves the following sequence:

- back end manufacturing of accessory products (1993-4)
- front end build of accessory products (surface mount technology transfer, skill transfer) 1995
- materials procurement, stockroom and storage management (planning, buying, vendor interface, minibank) 1996
- turnkey management (materials sourcing, materials procurement) 1997

Engineering know-how passes through the following steps:

- materials quality engineering (failure analysis, vendor development, vendor process characterization) 1996
- process/reverse engineering (internal process characterization, root cause analysis and design of experiments, statistical process control methods, product enhancement, prototyping, pilot manufacturing) 1997
- research and development procurement (phone systems, radio frequency technologies) 1998

A third example is in executive information technology training. Dell Computer has co-sponsored an "Executive Studio", a hands-on work experience and training facility for chief executives, with the West London Training and Enterprise Council (Manchester, 1998, p. xii). The studio gives senior managers real experience of using IT. To quote from Phil Blackburn, chief executive of the West London TEC:

> IT demands a new generation of senior managers. E-commerce is coming toward us like a tidal wave and senior management must be able to ride the wave. So the studio is not about IT awareness—but rather giving chief executives the confidence and competency to use IT directly.

The Motorola case is particularly instructive as a potential methodology, already piloted within the Malaysian environment, which could become the basis for a broad-based skill development program. The area of spin-offs and start-ups is another process about which much can be learned from local success stories. The example of Intel and Unico is a case study in the emergence of a rapidly growing, locally owned entrepreneurial firm which could provide clues into fostering the new firm creation process. Converting any of these pilot projects into methodologies for diffusion agencies is a crucial industrial policy role. Successful diffusion requires partnering of industry, government and educational institutions.

Shop-floor skill-formation diffusion agencies

Industrial transitions can be fostered by mission-driven by intermediary institutions (neither business enterprises nor government agencies) which form integral parts of regional and national business systems. Ignored by much of the industrial organization literature, these intermediary organizations can be established by industrial policy makers, by groups of enterprises, or by professional associations. They are an example of how the most effective industrial policy can often be conducted in the name of education and labor policies.

Technology diffusion and skill-formation work hand-in-glove in industrial transitions. The technology diffusion process depends upon the level of skill formation in the work organization of a region's enterprises. The pace is enhanced by a shared supplier base of SMEs that can achieve world-class performance standards in cost, quality, and time. In fact, every region that has made the transition to TM3 (see Table 1) has simultaneously incorporated a variant of the *kaizen* or continuous improvement model of work organization across a critical mass of SME supplier firms.

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 programs have a common feature: teacher training is designed into the program. Elsewhere we illustrated the theme with the examples of the JUSE[20] and the Japanese Human Relations Association[21] (Best, 1997c). Another outstanding model is the Training Within Industry (TWI) program.

TWI was developed in America but thoroughly refined in Japan. Some have argued that the most important export from America to Japan was the Training Within Industry program.[22] It deserves special attention as it illustrates both a successful shop-floor skill-formation diffusion program and successful institutional transfer.

The effectiveness of the TWI program was clearly demonstrated during the Second World War when the United States dramatically increased its production while at the same time deploying millions directly in the war effort. It did so by developing a training program for a new labor pool composed largely of women and recruits from non-manufacturing sectors. Undertaken by the Department of War and based on analysis of the most successful industrial training efforts around the nation, TWI broke down the training system to its basics. They made five important distinctions: knowledge of the work; knowledge responsibilities; job instructions (every supervisor has to be taught how to train other workers); job methods (every supervisor has to be taught the importance of methods, particularly the principle of flow); and job leadership

[20] JUSE was established in 1947 to promulgate quality control, statistical process control and total quality management, administers two journals, and publishes numerous books. PDCA, for example, has been introduced into numerous enterprises. Kaoru Ishikawa, who invented the fishbone, was a long term president of JUSE. The JUSE as much as any other single organization has provided Japanese enterprises with a continuous improvement approach to production and a participatory approach to industrial engineering (see Best, 1990).

[21] The JHRA specializes on continuous improvement methods. Kaizen tiean is a system for eliciting commitment from every worker to contribute to ongoing improvement. While the suggestion box system has long existed in America, it has become a powerful organizational tool in Japan, not for eliciting one big idea but for promoting participation. The ideas of participation is to involve everyone in a concept of work with the goal of productivity enhancement through the accumulation of numerous small improvements. A second key improvement in the suggestion box system has been to give authority for approval and implementation to the front lines. The idea is not to simply give a suggestion, but to implement a suggestion; this means educating and empowering work teams to control the process. The contrasting implementation capability is indicated by the fact that while 0.2 ideas per worker per year are submitted in the US, 20 ideas per worker per year are submitted in Japan (JHRA, p. xiii).

[22] This section draw heavily from Robinson and Schroeder, 1992.

training. The first two are company specific, the latter three are referred to as the 3 J's. The key to the program was the cascading effect by which the trained became trainers.

Post-war Japan understood it's value; particularly the Ministry of Labor who hired United States trainers laid off by the US Government. The Ministry continues to license a range of groups to teach the progam in companies. Toyota has their system, they call it TTWI (Toyota Training Within Industry). In Canon, every single trainer is certified in TWI.

The Penang Skills Development Centre, an industry-led, company and state government partnership to enhance manufacturing and technician skills plays a similar role in Penang (see Sidebar 3). Such an institution will continue to be critical in the context of a move to greater industrial innovation capabilities in Malaysia. Regional advantage will depend not only on innovation but on the diffusion, successful application and improvement of proven technologies. SMEs, the world over, depend on skill formation agencies such as the PSDC for best practice methodologies and the improvement of capabilities. Mr. Lim documents the areas of shopfloor strength and weaknesses in modern manufacturing practices in Penang plants. Clearly, the PSDC could play even a much wider role as SMEs begin the long process of manufacturing modernization.[23]

Visible Colleges: University and Industry Partnerships in Skill Formation

Equally integral to an organic, growing cluster is a set of dynamic interactions between the cluster and skill formation institutions. 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 depends upon growing the pool. William Foster of Stratus 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 development of both the Route 128 and Silicon Valley electronics clusters involved the simultaneous development of university departments, research institutes and curricula, on the

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[23] For an assessment of America's Manufacturing Extension Partnership, a national network of technology and business service providers see Shapira (1998).

one hand, and rapidly growing entrepreneurial enterprises, on the other. This dynamic is the hot-house environment that has nurtured techno-entrepreneurs, the drivers of the cluster dynamics.[24]

This captures the challenge of making transitions: without adequate graduates, new graduates can not be produced. Nevertheless they must be. This is the case in Penang. It will require the development of a plan in which companies, universities, regional and national government all make substantial contributions.

The range of incentives that attracted MNCs to Penang were successful but they are not appropriate for addressing the transition challenge. Incentives that mask economic fundamentals—incentives that if withdrawn, would not leave behind lasting economic activity in the region—must be avoided. Effective industrial policy is more about education policy and technology policy than about tax incentives.

Skills and schools are local, immobile resources. 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 is responsive collaboration with industry and government in skill formation appropriate to the region. The investment in skills takes time and strong relationships which cut across educational institutions and business enterprises.

Presently, Penang and Malaysia face a low-level, self-reinforcing skill formation trap with respect to graduate-level IT education. Without graduates, companies can not develop innovation capabilities and without industrial innovation, potential students do not see employment opportunities. This is the critical bottleneck facing Malaysian electronics.

The problem is that the process of skill formation is not being treated as a process requiring the same process integration infrastructure that is required in modern manufacturing. The idea of agile manufacturing is that customers and suppliers of raw materials have to be brought into the process. Only with an ongoing relationship with customers can the manufacturing process be made responsive to customer needs (we illustrated this above with Dell's produce to order strategy;); equally, only with close, consultative relationship with suppliers is it possible to implement JIT and new product development.

The idea of process integration is equally applicable to the skill formation process. It means that an institution has to be created that enables ongoing, consultative relations amongst the customers, in this case employers of graduates; the producers, in this case the educational institutions; and the suppliers of raw material, in this case the students. Another key producer in the skill formation process is the teacher, at both the secondary and tertiary levels. Out of these ongoing discussions a range of programs can be developed to increase the pool of students going in to IT programs; to advance the resources and curriculum responsiveness of the schools;

[24] The best Asian model for the development of techno-entrepreneurs is Taiwan (Wade, 1990; Dolven, 1998).

and to create opportunities for students and faculty to work and learn in companies and for companies to develop, jointly, awareness in schools of future opportunities.

Meeting the "tall order" will require institution building of this type which will, in turn, require a large commitment of government funding, local political leadership, and industry/education partnering. Here, industrial policy is simultaneously education policy. But often times the most successful industrial policy is education policy. This explains, in part, why planned industrial policy has not played a role in some of the most successful cases of regional industrial development such as Bangalore's software industry; Bangalore has numerous educational institutions (Balasubramanyam and Balasubramanyam, 1998).

Without a big push, the electronics industry risks staying trapped in a low skill generating and using trap.

Deliberation councils

Passive instruments such as tax incentives are not enough to foster industrial transitions in the knowledge-intensive economy. The challenge to government is to establish policy making capabilities that can reduce the risk and enhance the incentives for firms to make the long term investments required to build the requisite organizational capabilities. Serious cooperation between government and industry is required in the shaping of public policy. While the form of the cooperation will vary, the institution of the deliberation council can be effective in managing the interface between government and industry leaders to shape and achieve goals. A deliberation council has four main tasks (Campos and Root, 1996, ch. 4):

1. assist the government in formulation of strategies and policies;
2. establish a transparent forum to deliberate over the rules, regulations, and policies which impact on the industry and its profitability;
3. demonstrate commitment from government to give priority to long term investment in policy making as distinct to short term stabilization goals;
4. create a vehicle for developing the infrastructure required to advance regional and national production capabilities including skill formation, R&D, and technology management.

Penang has an infrastructure for deliberation councils. In fact, task forces have been created to respond to the crisis which include the leading firms in the region. The national government, working jointly with the Penang Development Corporation and both visible and invisible skill formation institutions, can play a integrative role in institution building to create the educational infrastructure to push Penang electronics to the next level of capabilities. This, in turn, would be a model for the other electronics regions of Malaysia and other emerging clusters.

Innovation and skill formation monitoring

Too often, industrial policy measures success and develops policy in terms of the conventional equilibrium economics paradigm. The only conceptual space for industrial policy in this paradigm is market failure; the role of public and private partnerships in fostering the whole range of capabilities and dynamics associated with the knowledge and innovation paradigm are obscured if even perceived. The [market-failure theory of industrial policy is anchored in the] equilibrium paradigm is not wrong; the problem is that the unit of analysis by which it defines the world is the *individual choices*. In contrast, the knowledge and innovation paradigm defines the economy in terms of *institutional activities*. Capabilities come into focus and dynamics are the norm.

The idea of dynamics means that no two choices are ever the same because the very act of making a choice sets feedback effects into motion that alter the environment. But the idea of dynamics is more than the introduction of time; dynamics means that learning is built into activities. Three learning dynamics are critical to industrial policy: intra-firm dynamics between productive capabilities and opportunities; inter-firm dynamics amongst firms as capabilities are developed and networks are reconstituted; and sectoral dynamics as new sub-sectors increase the techno-diversity of the cluster.

Targets of industrial policy and measures of success are paradigm dependent. Innovation, for example, is measured in the number of scientists engaged in the process of discovery, instead of part of ongoing activities that constitute the economy. The knowledge and innovation paradigm calls for a much greater range of indicators of innovation. Setting goals in this area and building private-public collaborative programs is critically important for the growth process.

The industrial innovation paradigm calls for metrics that can be used to target improvement and innovation opportunities. Metrics highlight the important from the unimportant and thereby focus attention and mobilize people around specific goals. Each of the following conceptual frameworks can be used to develop indicators appropriate to circumstances.

- the production capabilities spectrum (see Table 2)
- the technology management models and the associated production principles
- cluster dynamics (entrepreneurial firms, new firms, spin-offs, new sub-sectors, diversity)
- internal assessment exercises such as those used to certify vendors
- skill formation

Each of these offers measures for the purpose of enhancing production capabilities and system performance. Successful industrial policy depends upon developing simple, usable measures. For measuring cluster dynamics, for example, indicators of entrepreneurial firms and new firm creation are particularly important for targeting industrial policy. Entrepreneurial firms increase local productive capabilities and create spin-off opportunities; in contrast, subsidizing non-innovative but big firms can engender a Upas tree effect, hindering growth. Similarly, measures of spin-offs from existing companies in a region are monitoring a powerful driver of growth. This shifts energies away from attracting FDI to fostering local companies.

Sidebar 1: Strategy Statements in Second Industrial Master Plan: 1996-2005 and Seventh Malaysia Plan: 1996-2000

The Seventh Malaysia Plan includes a "…planned shift from the input- or investment-driven strategy…to one which is productivity-driven". The new strategy "…recognizes the centrality of human resources" and the need to "..enrich the science and technology (S&T) base in Malaysia" and "…incorporates proposals for achieving qualitative improvements such as promoting private sector participation in S&T development, nurturing of domestic innovations and inventions, and fostering better collaboration among research agencies, industry and universities" (Prime Minister's Forward to Seventh Malaysia Plan, pp. v-vi, EPU, 1996).

The 7MP stresses technology as a means of achieving the goal:

> In an increasingly competitive global environment, where technology has become the focus of new opportunities for investment and growth, the emphasis will be to fully exploit and utilize existing technologies, improve upon imported technologies, as well as generate indigenous technology (EPU, p. 447).

The *7MP* does not shift from continued reliance on foreign direct investment:

> The goal is to contribute much more to long-term sustainable growth, development and competitiveness in the economy. The *primary source of technology will continue to be foreign enterprises*, which will serve as a base to enhance Malaysia's participation in high level technology-intensive industrial activities and services" (italics added, p. 433, see also p. 439-445 where government policies are described).

The *Second Industrial Master Plan* is based on a "cluster-based Manufacturing ++ strategy".

> The *Manufacturing* ++ strategy for Malaysia will entail not only moving along the value chain but more importantly place emphasis on productivity-driven growth such that value-added per employee improves to a higher plane at all levels of the value chain (p.13)
>
> Cluster-based industrial development provides a basic framework which addresses the issue of market, linkages and networks and relates them to the underlying core competencies which are central to the competitiveness of industrial clusters (p.10).
>
> The IMP2 emphasizes moving beyond manufacturing operations to include R&D and design capability, development of integrated supporting industries, packaging, distribution and marketing activities (p.3)

The electronics and electrical (E&E) industry group, IMP2 emphasizes "…is **perhaps the only industrial sector which has developed the resemblance of an industrial cluster**" (p.14, bold in original.)

Sidebar 2: Transition Strategies: The Foreign Direct Investment Model

Best (1997c) describes three rapid growth institution-development models which have successfully driven such a transition: the Japanese and Korean model driven by large, domestically owned conglomerate-type business enterprises in close alliance with industrial policy strategies committed to developing indigenous technology management capabilities; the Taiwan "industrial district" model based on a proliferation of small and medium sized firms some of which become developmental firms and an industrial policy geared to a developing techno-entrepreneurs; and the Singapore model driven by local divisions of foreign owned multinational companies and a human resource oriented industrial policy designed to transfer capabilities from corporate headquarters to local divisions which, in turn, act as the hubs for regional production systems.

Malaysia has pursued a variant of the Singapore model in that the electronics industry is virtually entirely foreign owned. In the period 1984-89, Malaysia was the fifth largest recipient of inward FDI flows going to developed and Asian economies but became the second largest over the 1990-1994 period (Singh, 1998).[25] In absolute magnitudes annual FDI into Malaysia increased from an average of $.84 billion during 1982-87 to between $4-4.5 billions in 1991-93 (World Bank/UNDP, 1995, vol. I, p. 19).

The relation between the home country managerial characteristics of FDI, the external forces driving FDI, and technology diffusion calls for further examination. The large increase in FDI over the last decade is closely correlated to the growth in employment in electronics from 57 thousand in 1986 to 329 thousand a decade later. Thus FDI has a considerable impact on the production and organizational contours of Malaysian electronics and electrical products. For example, Singapore's investment is heavily concentrated and in third and fourth tier supplier firms in the Johor region with minimal technology management capabilities; its growth is associated with the transition of the Singapore manufacturing capabilities from mass production to automated and, increasingly, to flexible production with concurrent engineering and mature product redesign capabilities.

[25] Over the 1984-89 period, Singapore led with 28.3% followed by Hong Kong with 12.2%, the United Kingdom with 11.5%, the Netherlands with 9.9% and Malaysia with 8.8%; Taiwan received 3.3%, China 1.8%, Indonesia 1.6%, Korea 1.4% and India 0.2%. Over the 1990-1994 period Singapore remained the leader at 28.4%, followed by Malaysia at 22.4%, the Netherlands at 12.2%, China at 11.6% and the UK at 10.5% (Singh, 1998).

Japan and Taiwan, however, have been the largest investors over the 1991-95 period (EPU, 1996, p. 275). Much of Japanese MNC investment has been in consumer electronics and has been driven by the post-1986 appreciation of the yen, an increase in domestic production costs associated with yen appreciation, and trade friction between Japan and other advanced industrialized countries. Furthermore, the end of GSP tariff preferences for products made in Taiwan at the beginning of the decade have made investment in ASEAN countries attractive to MNCs selling to American and European markets.

The third largest source of FDI is the United States which has tended to be more concentrated in Penang and in electronic components and computers; it also seems to be driven by different company strategies and organizational dynamics and to have been subject to different relations with local authorities and enterprises. It is argued below that the Penang Development Corporation has played a pro-active role in the shaping of FDI into an emerging dynamic cluster with a regional competitive advantage in high-volume, automated production.

Scholars have argued that companies managerial characteristics are strongly affected by the social environment of their home countries (Bartlett and Ghoshal, 1989; Itagaki, 1997). Japanese multinationals, for example, reflect the lack of diversity in Japanese society and an over-concentration of information and authority at headquarters.[26] At the same time, Japanese MNCs commonly transfer soft technologies associated with workforce participation in shopfloor management such as JIT, TQM, and small-group activity associated with multi-product flow.

In any case, it is highly unlikely that FDI will continue to flow into Malaysian electronics on the scale of the previous decade whatever incentives may be offered. It is critical that new, complementary, approaches be pursued. Before turning to Penang we include a brief description of the links between Singapore's electronics cluster and the Johor region. Developing an industrial strategy for electronics in the Johor region will require a closer examination of these links.

Sidebar 3: Penang Skills Development Centre

The State Government of Penang and the Penang Development Corporation partnered with industry, particularly the MNCs, to establish the first industry-led training institution in Malaysia.[27] At a seminar organized by the American Business Council in September, 1987, the

[26] Many argue that Japanese FDI in Malaysia tends to be involved in minimal technology transfer (although others disagree but, if so, it may be related to the heavier concentration on consumer electronics and electrical products). It also appears that divisions of Japanese companies in Malaysia have ex-patriot top management and rely less on local managers. See Itagaki (1997).

[27] The material in this section is based on publications of the PSDC and an interview with its executive director Boonler Somchit.

problem of skilled manpower shortage was highlighted. In the process of a series of meetings with CEOs of MNCs the concept of a technical training center in Penang was developed. In April of 1989, the concept of the Penang Skills Development Corporation became a reality with the election of a Management Council which, in turn, garnered the pledge of 24 companies to become Founder Members. The mission of the PSDC is as follows:

> To be a Resource for the Promotion of the Shared Learning for Manufacturing & Service Industries by Providing Proactive HRD Initiatives to Strategically Support & Strengthen Business Requirements (PSDC, 1998, p. 3).

Nine years after its opening the PSDC has 81 member companies employing over 75,000 workers (PSDC, p. 1). The 21 member Management Council consists of 11 elected, 4 appointed, and 6 ex-officio members representing industry, government, and educational institutions. All companies are entitled to send members to the Training Committee, which is divided into two sub-committees which "…identify and recommend course work within a specific section (job enhancement and career advancement) of the overall training program". The training sub-committees are fora for defining training needs; they oversee an annual training needs analysis, prepare an annual training calendar, obtain feedback and evaluate the effectiveness of courses, encourage sharing of resources among member companies through the PSDC, and assist the Executive Director in funding efforts.

The participation of industry in the management structure of the PSDC has fostered a matching of skill demand and supply. Virtually co-located with member companies, the PSDC is easily accessed. Nearly 40,000 have been enrolled in courses which have grown from 32 courses offered in 1989-90 to 495 in 1997/8 (PSDC, p. 11).

Table 1. Five Cases of Technology Management

	Case	Production Principle	Application	Performance Breakthrough	Organizational Capability
TM 1	Armory	Interchang-ability	Replace Hand-fitters	Product Performance	Product Engineering, Special Mach. & Tooling
TM 2	Ford	Flow	Single Product	Cost	Process Engineering, Synchron.
TM 3	Toyota	Flow	Multiple Products	Cost, Quality, Lead Time	GT, Cellular Manu., Kaizen
TM 4	Canon	Flow, System Integration	New Product Dev., Generic Technology Integration	Product Innovation	Applied R&D, Proprietary Technology Dev.
TM 5	Intel	Flow, Systems Integration	New Product Concept, New System Design	Smart Products	Software Eng., Science & Technology Integration and Networking, System transitions

Source: Best (1998).

Table 2: Production Capabilities Spectrum

1. **Pre-flow, pre-interchangeability**: traditional craft production. This means, for example, that each drawer in a dresser is a unique fit. Craft production, by itself, offers no basis for flow. The task is to develop product engineering skills. Pre-TM 1.
2. **Interchangeability** without flow: Production that involves product engineering but lacks process integration engineering, hence low inventory turns and working capital productivity. TM 1.
3. **Single product flow**. These plants enjoy economies of speed but are dedicated to a single product or range of products with dedicated lines. Workers are not trained in continuous improvement, rapid changeover, or blueprint reading skills. TM 2.
4. **Single product flow with process innovation**: labor force includes maintenance and process control technicians who can identify and fix electronics problems in machinery. Next step is programming technicians and associate engineers that can identify and solve bottlenecks. This may involve reconfiguring design parameters at main office. Singapore in the mid-1980s, Malaysia in early 1990s. Redesigned TM 2.
5. **Multi-product flow**: the Toyota system which has spread to small and medium sized suppliers to MNC throughout East Asia. Kanban, JIT, and SMED are introduced in large plants. High throughput and flexibility are combined. TM 3.
6. **Multi-product flow with continuous improvement**. This involves Plan-Do-Check-Act or TQM at shop floor level and self-directed work teams. TM 3.
7. **Multi-product flow and new product development**: Japan and Taiwan both excell at concurrent engineering and design for manufacturability. TM 4.
8. **New product development and technology integration**: Japan's Toshiba and Canon are leaders in linking development to operations at the plant level and linking research in generic technogies to product development. Core technologies are developed, often via fusion in generic technology labs. Technology management involves world-wide sourcing of the existing technology base in pursuit of novel applications. TM 4.
9. **New product development and fundamental research**: 3 M, HP and Motorola have developed new forms of networking to identify new technology drivers for product development. Radical breakthroughs are pursued but within an organizational context of process integration. These companies are learning firms that emphasize knowledge workers and education at all levels. Motorola has 7 phases in self-directed team development and supplier development programs that emphasize partnering. TM 5.

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