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THE DEVELOPMENT OF TECHNOLOGICAL INNOVATION CAPABILITY IN DEVELOPING COUNTRIES: STRATEGIES OF EAST ASIAN NICs FOR CATCHING UP IN ELECTRONICS

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Documento elaborado pelo consultor Mike Hobday (Science Policy Research Unit/University of Sussex).

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EXECUTIVE SUMMARY

1. THE ACHIEVEMENTS OF EAST ASIAN NICS IN ELECTRONICS

This paper explores the competitive achievements of the four dragons or newly industrialising countries (NICs) of East Asia: South Korea, Taiwan, Singapore and Hong Kong, focusing on electronics and information technology. Following Japan, the four dragons have become formidable competitors in electronics. As a result of very rapid growth, electronics has become the largest industrial sector in three of the four NICs. In Hong Kong is the second largest. The growth in industrial output, employment and exports in electronics has helped each country move from poverty and low wages in the 1950s and 1960s to medium wage, full employment economies. In Singapore and Hong Kong, GNP per capita now is on a par with Japan's.

Although much of the industry is dependent on Japan for technology inputs, each country has substantially upgraded its technology base in electronics. For example:

- in South Korea, the largest manufacturer, Samsung, astonished observers in July 1990 when engineers presented samples of 16 megabit dynamic random access memory (DRAM) semiconductors to conferences in the US, ahead of the market leaders in both Japan and the US. By 1992 Samsung was ranked fifth among the world's DRAM producers and first in one and four megabit DRAMs. Other South Korean firms had also entered the DRAM market, with Goldstar and Hyunday ranking 12th and 13th in 1992. Twelve years earlier, South Korea had no significant market share in semiconductors; in order to overcome their traditional dependency on licensing, local firms have stepped up their in-house R&D efforts, acquired overseas high-technology firms and formed technology partnerships with leading foreign companies;

- in Taiwan, one of the leading computer makers, ACER, came second in the world with the 32-bit personal computer (PC) ahead of IBM and behind Compaq. In 1990 ACER employed around 500 R&D staff in electronics. It was the first company worldwide to develop a user-upgradable PC, which the buyer is able to upgrade by simply "plugging in" a new more powerful microprocessor unit;

- in Singapore, a large number of transnational corporations (TNCs) was attracted to produce consumer and industrial electronics because of its fully operational integrated services digital network, its efficient information technology infrastructure and high level human resources;

However, despite the general upgrading of the technology base the NICs are forced to manage structural weaknesses in their electronic industries. Dependence on Japan for technology inputs, components and market outlets is one set of problems. Another is each country's delicate balance of trade resulting from heavy imports from Japan. The tiny size of firms in Hong Kong and Taiwan prevents heavy corporate R&D spending. In contrast, the conglomerate structure of South Korean firms makes them relatively slow and inflexible in international markets, and has relegated them so far to relatively low value-added electronics goods. Finally, while the engineering base of each economy is strong, the NICs have yet to establish the research and scientific strength to enable them to compete with world leaders at the technology frontier.

2. SUCCESSFUL CATCHING UP STRATEGIES IN ELECTRONICS

The general economic achievements of the four dragons are well known. Less well understood are the strategies by which firms overcame market and technology entry barriers as they progressed from simple consumer electronics to more complex industrial goods and semiconductor components. The question of how East Asian firms succeeded in overcoming barriers to entry in electronics and initiated the process of rapid and sustained technological learning remains largely unexplored. Part of the answer to this question resolves around the efforts, abilities and strategies of latecomer firms in the NICs.

Latecomer firms are dislocated from the main internacional sources of technology and R&D. They operate outside the world centres of science and innovation and lag behind technologically. Their technology infrastructures are poorly developed, as are their policy organizations and educational institutions.

Such firms are also dislocated from the mainstream markets and demanding users in the advanced countries. They suffer from underdeveloped small local markets and unsophisticated users. Latecomer firms had therefore to develop outside the international clusters of demand and innovation.

Latecomer firms from East Asia overcame such disadvantages, acquired technology and became stronger competitors to the international electronics market. The path toward advanced information technology has been a painstaking gradual progression from simple manufacturing tasks in the 1960s to technology intensive industrialisation in the 1990s. Development success has relied primarily upon the efforts of locally owned firms, except for the case of Singapore. Government policies for education, competition and technology played a central role in each case.

In each case technology accumulation in electronics was linked to export and foreign channels of investment. Foreign buyers and OEM arrangements served a dual purpose. On the one hand they provided an outlet to the international market, assisting firms to overcome market entry barriers. On the other hand they served as a direct channel for technology transfer, allowing local firms to gradually learn electronics technology. OEM acted as a training school for many local companies. Other important foreign channels included foreign direct investment (FDI), joint ventures and licensing. Local firms from Taiwan and Hong Kong imitated foreign firms and supplied TNCs under subcontracting arrangements. These mechanisms were exploited by local firms to bootstrap their way into electronics markets. Korean firms used joint ventures and OEM arrangements to overcome entry barriers and accumulate technology.

3. POLICY IMPLICATIONS FOR DEVELOPING COUNTRIES

For other industrialising countries, the success of East Asian latecomer firms shows that entry barriers can be overcome. In the East Asian case, export orientation and export-led growth was intimately linked to technology assimilation and learning so as to overcome such barriers in spite of initial disadvantages. Local firms in the dragons exploited the various foreign market and technology channels, enabling them to follow and eventually catch up with the world market leaders in electronics.

While foreign channels provided the opportunity, local firms were the foundation upon which the dragons developed (with the exception of Singapore). Local firms generated most of the employment, exports and value-added in electronics. Local firms exploited the foreign channels of marketing and technology. Foreign investment was a necessary but insufficient condition for success. Local firms forced the pace and scale of the progress. The implication for other countries emerging from import substitution regimes, is that investment liberalisation alone may not be a sufficient condition for electronics development. The two largest dragons, Taiwan and South Korea, controlled and restricted the inflow of FDI. FDI was used judiciously to assist in the development process. Indeed, FDI only constituted a tiny proportion of total capital formation in these two economies.

Regarding the process of innovation in electronics, the experience of the dragons may well prove instructive for other countries. Although there were no rigid phases of development, there was a tendency for industry to move from simple assembly to more complex tasks involving production engineering, product design, prototype development and R&D. The path to advanced information technology was a gradual one - and still largely incomplete. For other countries, this suggests that to fully exploit the industrial development potential of electronics, complementary basic industrial and engineering skills are necessary (e.g. plastic moulding, electromechanical interfacing, precision machining and fine engineering). These skills are needed to produce electronic goods and systems. Their accumulation is also a route towards more complex, higher value-added electronics and information technology.

This overlap of technological paradigms has implications for training. It suggest that for electronics and information technology, a strong supply of pre-electronic craft and production engineering skills is needed. Electronics manufacturers in the dragons benefited from government policies which emphasised craft and engineering training in academic institutes and government laboratories connected with industry.

Regarding industrial structure and strategy, there was considerable variety among the four dragons. Taiwan, for instance, relied on a multitude of small, fast moving firms supplying niche markets. Their experience suggest that some of the disadvantages of small scale can be overcome in electronics and that there are proven alternatives to the Japanese and South Korean large firm "models" of electronics development.

Regarding industrial policy, three of the four dragons (except Hong Kong) carried out systematic policy intervention (e.g. tax breaks, subsidies and marketing assistance); South Korea and Taiwan also carried out import-substitution and FDI restrictions.

Finally, the experience of the four dragons highlights the role of government in fostering the electronics industry in a developing country in the following ways:

- government policies of various kinds (including targeting) have had a profound influence on the paths of technological achievement in all countries;

- in South Korea, these policies included procurement, subsidies, market protection and financial incentives to local firms;
- in Singapore, which relied strongly on foreign capital, government attracted TNCs by incentives, targeted training schemes, and infrastructural developments in telecommunications and transport;

- in Taiwan, the government has promoted technology development through various joint ventures;

- even in Hong Kong, the only country to follow a laissez faire policy, government was important insofar as implementing a very modern information technology-based infrastructure;

- education and vocational (specially engineering) training played an important role in all dragons.

INTRODUCTION

This paper explores the competitive achievements of the four dragons of newly industrialising countries (NICs) of East Asia: South Korea, Taiwan, Singapore and Hong Kong, focussing on electronics and information technology[1]. Following Japan, the four dragons have become formidable competitors in electronics. As a result of very rapid growth, electronics has become the largest industrial sector in three of the four NICs. In Hong Kong it is the second largest. The growth in industrial output, employment and exports in electronics has helped each country move from poverty and low wages in the 1950s and 1960s to medium wage, full employment economies. In Singapore and Hong Kong, GNP per capita now is on a par with Japan's[2].

The general economic achievements of the four dragons are well known. Less well understood are the strategies by which firms overcame market and technology entry barriers as they progressed from simple consumer electronics to more complex industrial goods and semiconductor components. The purpose of this paper is therefore to explore how "latecomer" firms from East Asia overcame barriers to entry, acquired technology and became strong competitors in the international electronics market. Special attention will be paid to the paths and mechanisms of technology accumulation as firms "learned" to innovate with electronics. The paper attempts to show how patterns of technology accumulation in electronics were closely linked to export marketing channels and the export-led strategies of each of the four NICs.

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1 Normally, the definition of electronics includes consumer goods, semiconductor components, computer and telecommunications equipment and other hardware. Information technology is used to describe the generic technology for controlling and storing information, including both software and hardware inputs. It is also used to describe the range of new services, including computer-computer communications, telecommunications networking, value-added data services and the software required for these services. These definitions are used in this paper unless otherwise stated. Also note that the four "dragons" are sometimes called the four "tigers".

2 South Korea and Taiwan lag behind the two "city states" in terms of GNP per capita. Each NIC has experienced very rapid wage rates, enabling them to jump up the GNP ranking of nations. See Wade (1990:35) and James (1990:4) for historical achievements of the NICs.

Part 1 begins by providing some indicators of achievement in electronics technology in each of the four dragons. Although much of the industry is dependent on Japan for technology inputs, each country has substantially upgraded its technology base in electronics. Part 2 offers a preliminary conceptual framework to explain how latecomer firms caught up in electronics technology and entered international markets. A simple learning/diffusion model is proposed to illustrate the connection between export growth and technology development. Part 3 provides examples of corporate strategies in electronics, showing how leading firms entered the industry and acquired technology. Part 4 turns to government policies, touching on competition, trade, foreign investment, education and technology development programmes.

The conclusion argues that the path toward advanced information technology has been a painstaking gradual progression from simple manufacturing tasks in the 1960s to technology intensive industrialisation in the 1990s. Development success has relied primarily upon the efforts of locally owned firms, except for the case of Singapore. Government policies for education, competition and technology played a central role in each case.

1. INDICATORS OF TECHNOLOGICAL ACHIEVEMENT

1.1. Selected Achievements of Market Leaders

Considerable variety exists among the four dragons in terms of technological strategy and achievement in electronics. The following examples of recent advances serve to illustrate the technological dynamism of leading firms and the absorptive capacity of the four dragons in electronics and information technology.

The largest South Korean manufacturer, Samsung, astonished observers in July 1990 when engineers presented samples of 16 megabit dynamic random access memory (DRAM) semiconductors to conferences in the US, ahead of the market leaders in both Japan and the US, not to mention Europe. Ten years earlier, South Korea had no significant market share in semiconductors (the key components for electronic goods). By 1990 Samsung had caught up in DRAMs, one of the most challenging and difficult areas of semiconductor design and manufacture. By 1992 South Korean firms commanded a 12.1% share of the world market for memory semiconductors, including 19.7% of the (then) mainstream technology, the four megabit DRAM. Samsung was ranked fifth among the world's DRAM producers and first in one and four megabit DRAMs, according to the market consultancy, Dataquest Inc.[3]. Other South Korean firms had also entered the DRAM market, with Goldstar Electron and Hyundai Electronics Industries ranking 12th and 13th in the world in 1992[4]. Samsung and Goldstar both planned to invest around $1bn each in new megabit DRAM manufacturing facilities in 1993.

There are many such indicators of the growing competence of South Korean electronics producers in world markets. In order to

3 See *Business Week*, 30 nov. 1992, p. 70-71, for a full report.

4 Overall sales of the Korean *chaebol* in 1990 were: Samsung $43.4bn, Hyundai $39.6bn, Lucky-Goldstar $25.0bn and Daewoo $16.0bn. These figures include non-electronics output (*IEEE Spectrum*, june 1991, p. 51).

overcome their traditional dependency on licensing, local firms have stepped up their in-house R&D efforts, acquired overseas high technology firms and formed technology partnerships with leading foreign companies. In 1985, Samsung set up a semiconductor research facility in Silicon Valley to keep abreast of technological change. In 1991 it invested around 9% of its total sales in R&D, in line with the R&D spending of the leading Japanese corporations (Koh, 1992:28-29). During the 1980s Samsung, Daewoo and Goldstar set up manufacturing facilities in western markets and substantially improved their domestic R&D capabilities[5].

In Taiwan, one of the leading computer makers, ACER, came second in the world with the 32-bit personal computer (PC), ahead of IBM and behind Compaq. In 1990 ACER employed around 500 R&D staff in electronics. It was the first company worldwide to develop a "user-upgradable" PC, which the buyer is able to upgrade by simply "plugging in" a new more powerful microprocessor unit. ACER started up in 1976 with 11 engineers. By 1992 ACER's sales were in the region of $1.2bn (*Electronic Business*, feb. 1992, p. 77). ACER developed the first Chinese operating system and contributed its own four, eight and sixteen-bit PCs to the marketplace. By 1990 it produced 32-bit PCs in Taiwan and had offshore manufacturing plants in Holland and Malaysia. In the following year the company formed a joint venture with Texas Instruments of the US (partly funded by the Taiwanese Government) to produce advanced DRAMs within Taiwan to help overcome local industry's import dependency on this particular component.

Other leading electronics firms in Taiwan include Tatund (with sales of $1.150m in 1990), Sampo ($537m), Mitac ($188m) and United Microelectronics Corporation ($148m) (*IEEE Spectrum*, june p. 51). In 1991 twelve locally owned firms produced and designed integrated circuits in Taiwan. The computer maker Mitac formed an alliance with Intel of the US in 1992 to produce a leading edge

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5 For examples, see Koh (1992) and Bloom (1991).

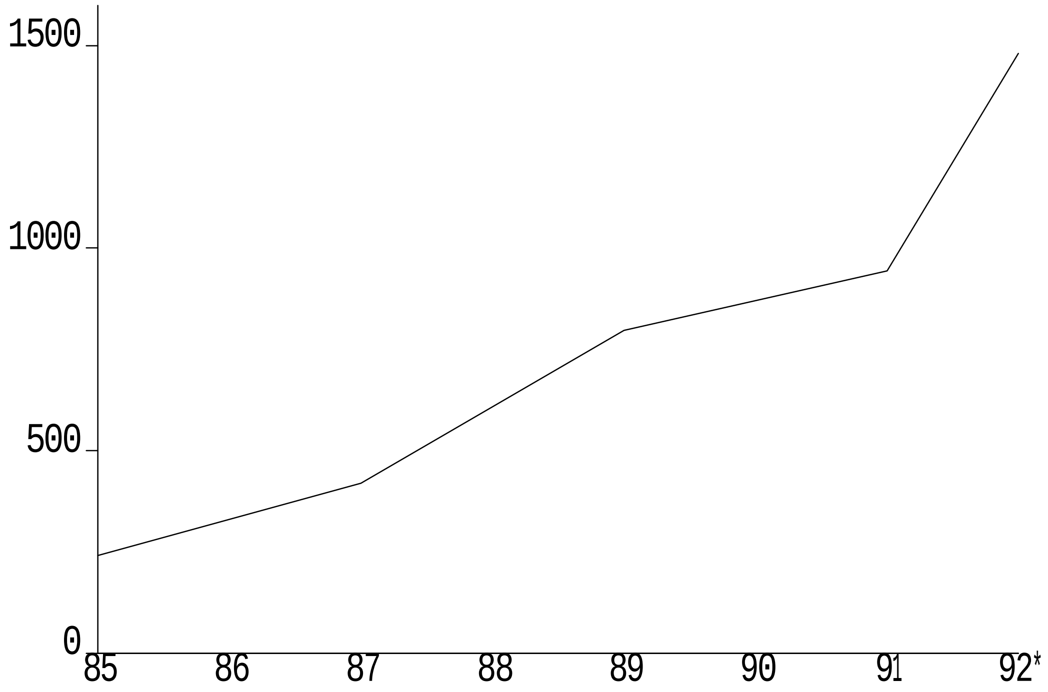
microprocessor unit for PCs, the 80586 CPU (*The China Post*, 31 july 1992, p. 9).

Government support has been stepped up recently to help Taiwanese firms acquire advanced information technology. The Industrial Technology Research Centre (ITRI), established in 1973, today has a budget of around $400m per annum and employs 5,200 people of which about 2,200 are engaged in electronics (Interview ITRI 1992). Under ITRI, the Electronics Research Service Organisation (ERSO) has had a budget of around $100m per annum since 1986 (Chaponniere & Fouquin, 1989:49). ERSO runs projects in many areas of advanced electronics. It recently received from Government around $120m to carry out R&D into high definition television R&D, involving five laboratories and several local firms. Its aim is to keep up with the evolving technology and market standards. Recently, the Government spent around $280m on advanced (sub-micron) semiconductor technology, helping to attract back many engineers and scientists trained (mainly) in US corporations and universities.

FIGURE 1

FLOW OF TECHNICALLY TRAINED TAIWANESE RETURNING TO TAIWAN

(Numbers of Engineers)



Source: original data from Taiwanese Government.
* Business Week estimate,
Cited in *Business Week,* 30 nov. 1992, p. 76.

As a result of Government projects and the rapidly expanding industry, thousands of engineers have returned to Taiwan (Figure 1). By 1992 there were so many former Bell Labs. employees working in Taiwan's electronics industry, that around 120 of them formed the Taiwanese Bell System Alumni Association. (*Business Week*, 30 nov. 1992, p. 75-76).

Singapore is probably best known for its fully operational integrated services digital network (an advanced fully digital telecommunications system) and its efficient information technology infrastructure, widely used in its sea and air ports, corporate trading, government and financial services. This infrastructure is part of the reason why large numbers of transnational corporations (TNCs) are attracted to the country to produce electronics. Unlike the other dragons, foreign TNCs dominate Singapore's electronics sector. Much of Singapore's recent economic growth has resulted from consumer and industrial electronics production. Output of electronics amounted to around $16.6bn in 1991 (exports were $15.0bn). Employment in electronics stood at 124,000 in 1991. In that year, Singapore produced around one half of the world's hard disk drives (roughly $4.1bn in sales). US firms such as Seagate, Connor and Maxtor began production in the early 1980s, expanded capacity and developed advanced manufacturing processes locally. In the case of Connor, the Singapore plant became its world centre for advanced manufacturing technology. The local Singapore director was placed in charge of transferring technology to Scotland and Malaysia (Interview with Connor Singapore, 1992).

Similarly, companies such as AT&T Consumer Products Pte Ltd. make and design top-of-the-range cordless telephones and other advanced consumer goods in Singapore, usually for export. In semiconductors, some TNCs have established wafer fabrication facilities in Singapore (e.g. SGS-Thomson, Hewlett Packard and Texas Instruments). Over time, the TNCs have upgraded their technological activities and transferred substantial amounts of technology from their parents to their subsidiaries.

Hong Kong is perhaps the weakest NIC in technological terms. Overall it spends only 0.05% of GNP on R&D, compared with 2.0% in South Korea (*Business Week*, 30 nov. 1992, p. 67). However, the country has a fully digital telecommunications infrastructure, one of the most advanced in the world. It recently established a new Hong Kong University of S&T (HKUST is known as the "MIT of Asia") at a cost of $450m. HKUST has hired high level staff from US firms and universities. It has research links with Motorola, Texas Instruments and Hewlett Packard, among others. By 1992 HKUST had attracted 2,200 students, 640 faculty staff and funds for a further 5,000 students (*Business Week*, 30 nov. 1992, p. 77).

Some firms in Hong Kong have scored successes in high technology niche markets. Varitronix, with expected sales of $45m in 1992, produces customised liquid crystal displays for use in Mercedes-Benz cars, miniature terminals and other advanced electronics products. Johnson Electric Holdings, with sales of $167m in 1991, supplies Chrysler, Black and Decker and Philips with micromotors. It is now the second largest supplier of micromotors after Mabuchi Motor Co. of Japan (*Business Week*, 30 nov. 1992, p. 71). Porro Technologies exports its own brand of workstations to Australia and the Pacific Rim. Other firms have designed sophisticated fax machines, cordless telephones and small screen colour televisions. Hong Kong's electronics firms tend to be very small. Eighty percent employ less than 50 staff. Larger firms include Video Technology, with sales of $287m in 1989 and Tomei Industrial with sales of $198m in 1989 (*IEEE Spectrum*, june 1991, p. 51-52).

1.2. Structural Weaknesses and Limitations in Electronics

Despite the technological and market successes of vanguard companies in the four dragons, there remain significant structural weakenesses in their electronics industries. Only a small minority of leading firms boast the technological achievements noted above. Most firms could not be described as "high technology". They produce relatively simple, consumer and industrial electronics based on the advantages of low cost engineering and management. As wages have risen in each of the four dragons, firms have relocated low end production into China and other poorer Asian economies such as Malaysia, Indonesia and Thailand. Most firms in Taiwan and Hong Kong are too small to fund extensive design or R&D. They remain behind the technology frontier, often making goods often under sub-contracting or original equipment manufacture (OEM) arrangements.

Under OEM a local firm produces a finished product to the specification of a foreign buyer (usually a large TNC). The foreign firm then markets the product under its own brand name, through its own distribution channels (hereby capturing the large post-manufacturing valued-added). OEM sometimes involves the foreign partner in the selection of capital equipment, the training of managers, engineers and factory workers. The arrangement usually involves a close technological relationship between the firms. OEM can act as an important 'training school' for local firms by which production and design techniques are absorbed. However, the junior partner is subordinated to the decisions of the TNC and dependent on the foreign company for technology, components and market channels.

Partly as a result of extensive OEM arrangements, the dragons are dependent on Japan for technology, components, machinery and capital goods inputs. In 1990 the four NICs imported around $57bn worth of goods from Japan (*Fortune*, 7 oct. 1991, p. 158). Three of the four NICs imported more goods from Japan than did the UK in 1990. Singapore, the exception, imported roughly the same amount as the UK. Each of the four countries had a negative trade balance with Japan through the 1980s, usually balanced out by their trade surplus with the US and Europe (Chaponniere, 1992:73). Despite their notable export record, the balance of payments position of the four NICs is therefore delicate. For example, in 1990 South Korea, Hong Kong and Singapore had overall trade deficits. The only dragon with a trade surplus was Taiwan.

High technology inputs constitute a large proportion of imports. In 1991 South Korea imported around $21bns' worth of high technology industrial goods from Japan, resulting in a trade deficit with Japan of $8.8bn. Similarly, Taiwan' deficit with Japan reached $9.7bn in 1991 (*Business Week*, 11 may 1992, p. 24-25). Firms and policy makers in the NICs have taken steps to reduce their technological dependence on Japan. Taiwan's Ministry of Economic Affairs has put forward a five year plan to achieve self-sufficiency in 66 key products and components currently imported from Japan. South Korea prohibits 258 Japanese products including camcorders and the Sony Walkman. South Korean firms have made large investments in key technologies to reduce their reliance on Japanese firms.

Korean firms' OEM strategies, coupled with the huge size of the *chaebol* conglomerates, has confined companies to relatively low value-added, large volume, mass markets. OEM arrangements have limited the scope of Korean firms in international markets, forcing them to rely on Japanese firms for semiconductor components, capital goods and distribution outlets. Recently, Samsung and others have attempted to develop their own brand images abroad by advertising, producing higher quality goods and locating production near to customers. However, in 1988 OEM accounted for some 60% to 70% of Korean electronics exports (Jun & Kim, 1990:14).

Similarly, in Taiwan OEM accounted for around 43% of production in computers and related goods in 1989 (III, 1991:39-43). The largest Taiwanese electronics firm Tatung exported around half of its output of colour televisions and personal computers under OEM arrangements in 1991.

South Korean firms are especially dependent on licensing and technical agreements for key components. For instance, in 1989, Hitachi of Japan supplied manufacturing knowhow to Goldstar for 4 and 16 megabit DRAMs. Among the South Korean firms only Samsung has developed its own DRAM technology in house. Goldstar and Hyundai rely on licenses from Japanese firms. Samsung formed a licensing deal for the advanced RISC (reduced instruction set computer) microprocessor from Hewlett Packard of the US, and is weak in other semiconductor fields such as applications specific integrated circuits (ASICs) and static random access memories (SRAMs) (*Electronics Times*, 24 aug. 1989, p. 8).

Turning to the dragons information technology and telecommunication infrastructures, while the two small city states of Hong Kong and Singapore enjoy highly advanced infrastructures, this is not the case for Taiwan and South Korea. The two largest NICs both suffer from infrastructural bottlenecks, not only in telecommunications and information technology, but also in transport and energy. Large spending plans are underway in Taiwan and South Korea to improve their basic infrastructures.

With progress, factor cost advantages have shifted in the NICs. The four dragons are no longer low wage areas. Today, their major cost advantage over the developed countries is low cost engineering and management. In Singapore, for instance, the main universities, polytechnics and training institutes (including the National University of Singpore and Nanyang Technological University) together supply around 22,000 engineers and craftsmen per annum, representing an annual output of roughly 38 per 100,000 population, one of the highest per capita levels worldwide[6]. In each of the dragons, the abundant supply of low cost, high quality engineering talent has enabled industrial expansion of engineering intensive goods such as hard disk drives, complex peripherals, advanced consumer goods and microcomputers.

6 1991 data cited in Singapore Investment News (1991:10). The abundance of high quality engineers is discussed in Part 4.

By contrast, the supply of research scientists and engineers is low in the NICs. In 1990 South Korea had around 33 research scientists and engineers per 10,000 workers, Taiwan had 43, and Singapore only 28 per 10,000. This compares with 87 per 10,000 for Japan, 77 in the US, 56 in West Germany and 44 in Switzerland. In addition, expenditure on R&D as a percentage of GDP in each of the four dragons lags behind most developed countries[7].

To sum up, despite the general upgrading of the technology base the NICs are forced to manage structural weaknesses in their electronics industries. Dependence on Japan for technology inputs, components and market outlets is one set of problems. Another is each country's delicate balance of trade positions resulting from heavy imports from Japan. The tiny size of firms in Hong Kong and Taiwan prevents heavy corporate R&D spending. In contrast, the conglomerate structure of South Korean firms makes them relatively slow and inflexible in international markets, and has relegated them so far to relatively low value-added electronics goods. Finally, while the engineering base of each economy is strong, the NICs have yet to establish the research and scientific strength to enable them to compete with world leaders at the technology frontier.

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7 For detailed evidence see NSTB (1991:12-17).

2. EAST ASIAN EXPORT-LED TECHNOLOGY DEVELOPMENT - A SIMPLE MODEL

2.1. The East Asian "Latecomer" Firm

Despite their difficulties, each of the dragons has made historically unprecedented economic and technological progress since the 1960s, especially in electronics. In Hong Kong, for instance, exports of electronics increased nearly threefold from $2.8bn in 1981 to around $7.5bn in 1990[8]. Although Hong Kong is probably the weakest technologically of the four dragons, even here many local firms are now able to design their own consumer electronics and computer products. Some work in partnership with OEM buyers, translating complex technical specifications quickly into new product designs for manufacture.

Asian firms have not only achieved a remarkable upgrading of their electronics capabilities but they have also narrowed the technological gap between themselves and the market leaders in Japan, the US and Europe. Some, such as Samsung and ACER, have overtaken the traditional market leaders in some areas. There can be little doubt that substantial and rapid technological learning has taken place at the firm level in each country since the days of poverty and underdevelopment in the 1950s and 1960s.

One largely unexplored topic, is the question of how East Asian firms succeeded in overcoming the barriers to entry in electronics and initiated the process of rapid and sustained technological learning. Part of the answer to this question revolves around the efforts, abilities and strategies of "latecomer" firms in the NICs. (The issue of the latecomer firm is explored in Parts 2 and 3. Relevant government policies are touched on in Part 4). The latecomer firm can be defined in terms of two sets of competitive disadvantages facing East Asian companies, or "would be" start-ups:

8 Fok (1991:258), current prices.

First, latecomers are dislocated from the main international sources of technology and R&D. They operate outside the world centres of science and innovation and are behind technologically. Their technological infrastructures are poorly developed, as are their policy organisations and educational institutions.

Second, latecomer firms are dislocated from the mainstream markets and demanding users in the advanced countries. They suffer from underdeveloped small local markets and unsophisticated users. Many studies show the importance of user-producer linkages to innovation. The importance of user-producer "clustering" in industrial development is stressed in various ways by Marshall and Vernon, and more recently by Freeman, Porter and Lundvall[9]. Latecomer firms had to develop outside these international clusters of demand and innovation.

Very little is written or known about how latecomer firms from the NICs overcame these disadvantages, forged inroads into advanced markets and began their process of rapid catch-up learning. Therefore, the following section offers a simple preliminary framework as hypotheses for further exploration.

2.2. Export-led Technology Development: A Simple Framework

Figure 2 suggests a framework for analysing the nature, direction and major factors in the process of technology development by latecomer firms in the East Asian NICs[10]. The left hand vertical axis represents total exports and employment in the electronics industry for each country. As exports and employment rise, wages and other costs are assumed to increase as a result

9 See for instance Marshall's work on industrial districts (1890: Chapter 10) discussed by Freeman (1990), Vernon's study on externalities (1960), especially Chapter 5 "External Economies", Lundvall's (1988) study on user-producer interaction and Porter's (1990) study on the competitive advantage of nations.

10 The scheme is largely based on field research by the author in East Asia. Firms, government agencies and academic institutes in each of the four NICs were interviewed and data were collected on the history and growth of electronics in each country. Some supporting evidence is put forward in Parts 3 and 4. However, the scheme should be viewed as initial arguments for testing, rather than final results.

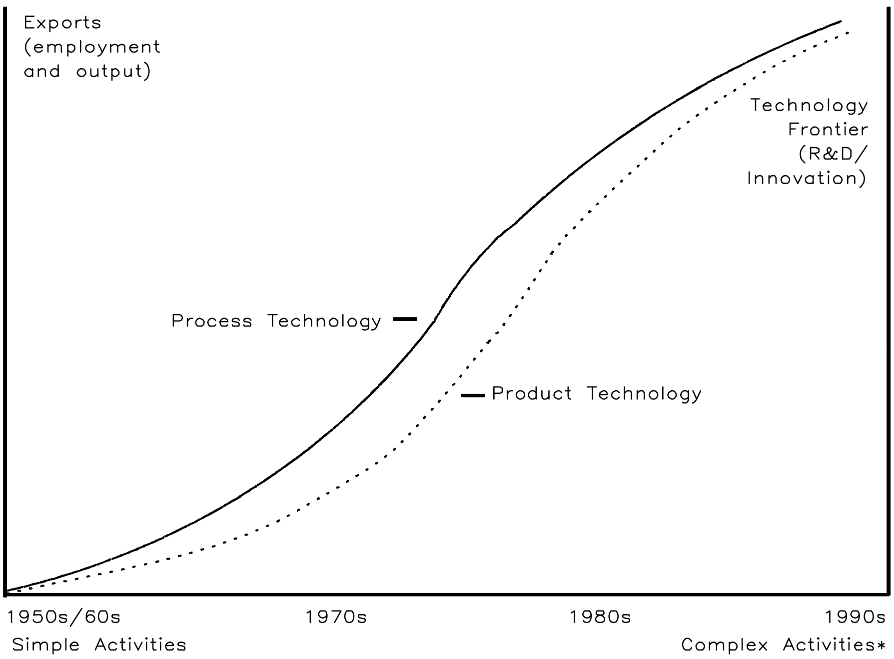
of bottlenecks, shortages and capacity limitations. The horizontal axis represents technology accumulation through time, beginning with simple activities such as assembly and graduating towards more complex tasks such as process adaptation and eventually development and research.

It is important to emphasise that no rigid or linear progression occurs through time. R&D may begin fairly early on in the scheme and there may be considerable feedback between early and later stages[11]. However, the model suggests that there is a general tendency among firms to begin with simpler tasks and accumulate capabilities systematically, in a path dependent, cumulative manner, with skills and knowledge gradually building on each other.

The S-shaped diffusion curve is used to suggest that within each country there will tend to be a start-up, take-off, growth and maturation phase in electronics. During the start-up period of the 1950s and early 1960s, firms slowly entered into the new emerging industry. As they were sucessful, others followed in a Schumpeterian "swarming" fashion. This led to a take-off of the industry as a whole during the late 1960s and 1970s. Eventually, industrial growth could slow down as larger market segments (e.g. consumer electronics) mature, bottlenecks occur, wages rise and the technology frontier is reached. However, there is no reason why the curve should follow this particular path. This will depend on the strategies and learning abilities of the latecomer firms. Swarming may begin at the initial stage. Export growth may not reach bottlenecks at any particular stage. As wages rise the local market may begin to absorb a larger share of total production (as occured recently in the Korean electronics and automobile cases; EIU, 1990:23). Also, as in the case of the four NICs, firms may overcome the rising labour cost problem by relocating production overseas to lower cost areas and concentrating on higher value-added production at home.

11 Forrest (1991) provides a useful summary of simple and complex innovation models incorporating feedback loops and external factors, such as policy and the macroeconomy.

FIGURE 2
LATECOMER FIRMS - EXPORT-LED TECHNOLOGY ASSIMILATION FROM BEHIND THE TECHNOLOGY FRONTIER



Process technology	Simple Assembly	Process Adaptation	Incremental Improvements	Process Development	Applied Research	Process R&D
Product technology	Assessment Selection	Reverse Engeneering	Prototype Development	Design for Mfr.	Design	New Product R&D

* No stages or linearity implied, but a general tendency to catch up cumulatively, through time with capabilities building systematically upon each other.

In Figure 2 the technology frontier is represented by the right hand vertical axis. It is defined here simply as the position at which substantial R&D is required to generate new product or process innovations. This is a moving frontier occupied by leading (e.g. Japanese and US) TNCs at any given time. Through time, the latecomer firms gradually narrow the technology gap between themselves and the leaders. By the 1990s, some leading firms (e.g. Samsung and ACER) reached the frontier in at least some product lines. At this phase, substantial investments in R&D were required for them to compete with the international market leaders. At the frontier stage, normal innovation models will begin to apply[12]. At this stage, R&D becomes an early and central part of the innovation process. It is worth pointing out, that this scheme reverses traditional linear ideas of innovation, and contrasts with complex feedback models which place R&D at the centre of corporate innovation. *The route to the exploitation of science and technology on the part of latecomer firms is the reverse of theories which stress R&D or place R&D at the beginning of the innovation process*. R&D generally occurs in the latter stages of a catch-up learning path beginning with simple tasks such as labour intensive assembly.

Although R&D may not be central to the initial activities of latecomer firms, innovation is assumed to occur throughout the process of catching up. This type of "behind-the-frontier innovation" (e.g. waste reduction and recycling, workforce multiskilling, cost reduction, smart designs for manufacture, product redesigns and process engineering improvements) is vital for catch-up development. Indeed, continuous innovation is a necessary condition by which latecomer firms narrow the technology gap between themselves and the market leader - otherwise firms merely "keep up" instead of "catch-up". Innovation is conditioned by factor prices (e.g. cheap labour and costs) and their relative changes, the initial capital scarcity

12 That is, in so far as they apply at all. Forrest (1991) provides criticisms of a range of innovation models. Criticisms include the assumption of linearity and the failure to include feedback loops and policy factors. See Utterback & Abernathy (1975) for their classic innovation model.

and above all the need to export. The tiny size of local markets forces firms to learn to export to survive. Firms initially compete intensely with each other for export orders on the basis of cost and speed of delivery. As time progresses, firms compete more on quality, reliability and own-design capabilities. Fierce competition generates local innovations along the lines of process improvements and adaptations, product design and production engineering.

Not all firms need progress in the above manner. New start-up firms (e.g. ACER) may "jump in" at advanced levels, missing out the early stages. As the technological infrastructure and overall base of human skills (i.e. absorptive capacity) improves, new companies may by-pass earlier stages. Indeed, this process is essential to the take-off and rapid growth of the industry. Spin-offs from older firms, large firm diversification and new experimental start-ups constitute the growing industrial base. In the case of South Korea new divisions were set up by the conglomerates. In Taiwan and Hong Kong large numbers of "returnees" from US firms have proved to be an important entrepreneurial resource during the 1980s[13].

The use of a diffusion curve is not meant to imply that there is any "automatic" process by which growth and technology accumulation occurs. On the contrary, the central mechanism by which the successful NICs grow is assumed to be the learning efforts of local firms[14]. A sustained and systematic learning effort is required by firms to assimilate foreign technology, build up new competences and catch up with market leaders. Learning begins with simple tasks such as assembly. Later on firms learn to stretch production capacity, to change and improve

13 Interviews were carried out by the author at Hscinchu Science-based Industrial Park in Taiwan in 1992 with a sample of 8 electronics start-up firms. Each firm had at least one or two US-trained senior directors involved in the start-up and running of the companies. Usually trained in engineering, these directors kept close business contact with their former employers in the US.

14 The importance of learning to late industrialisation is born out by Amsden (1989) for South Korea and Vogel (1991) for each of the four dragons. Fransman and King (1984) provide a collection of studies which show the importance of learning to technological development. Malerba (1992) defines learning and illustrates its economic significance.

production processes and to design and modify products. Eventually, the leading firms build up in-house R&D capabilities to enable them to compete on the technology frontier with major international companies[15].

Learning occurs not only at the technological level but also at the marketing level. Firms learn to package, distribute and market their goods, spurred on by the opportunities for increasing the value-added[16]. Some begin by establishing marketing departments to serve local markets or by setting up small marketing "outposts" in the advanced countries (Wortzel & Wortzel, 1981). Marketing, like technology, involves substantial investments in learning skills and organisation. Ultimately, the leading firms establish their own brand images (e.g. Hyundai and Lucky-Goldstar of Korea) abroad and advertise directly to customers in the advanced markets. By this stage, they are indistinguishable from other market leaders.

The model also postulates a relationship between process and product technology. Firms begin initially by selling production capacity to TNCs or foreign buyers. This requires the absorption of basic manufacturing, technician and management skills. Process innovation will begin to occur after the basic production operation capabilities are learned. Product capabilities are assumed to follow. After firms accumulate process innovation skills, they seek to improve the quality of products. They may begin to modify designs to ensure "design for manufacturability". Feedback occurs from product to process and vice versa in the catch-up process.

The latecomer firm is motivated by profit and market expansion opportunities. Vogel (1991) speaks of a sense of economic and political "urgency" among NIC firms and governments, as most adults recall the experiences of underdevelopment and

15 The exploitation of foreign channels of investment, technology and marketing is central to the development strategies of firms in the four NICs. This discussed in Part 2.3.

16 For an evidence and analysis of the assimilation of marketing skills by East Asian firms see Wortzel & Wortzel (1981).

poverty. They are driven to maintain the momentum of industrialisation in order to sustain the unprecedented new levels of prosperity. Entrepreneurs rush to compete as new market opportunities emerge. In electronics and information technology, technological learning is triggered by the opportunities and threats posed by the rapidly moving frontier. The opportunities lie principally in the rapidly expanding markets for electronics goods and systems. The threat lies in loosing market by failing to keep up technologically. As more East Asian firms approach the technology frontier in the 1990s there is a need for ever more advanced technology and research capacity. As discussed in Part 4, this need has led governments in each of the dragons to increase R&D expenditures and to upgrade their science and technology facilities in universities and government-run research laboratories.

To sum up, the simple model attempts to describe the dynamic relationships between the major factors which stimulate catch-up progress. Firms, entrepreneurial ability and rapid technological learning are central to progress in electronics.

2.3. Exploiting Foreign Channels of Export Marketing, Investment and Technology

In order to enter international markets and obtain foreign technology, latecomer firms utilise or "exploit" foreign channels of technology and exports. Only by building up such channels can firms overcome the two sets of latecomer difficulty described in part 2.1.

2.3.1. Foreign buyers

Some of the main foreign channels for both market and technology development in East Asia were large foreign buyers. In 1974 a study by Angus Hone showed that many local firms sold their goods to large buying houses from Japan and the US. The Japanese *Zaibatsu* buyers (e.g. Mitsubishi, Mitsui, Matubeui-Ida and Michinen) set up buying operations in the NICs to purchase cheap goods, as wages rose in Japan in the early 1960s. US retail companies (e.g. J.C. Penny, Macy's, Bloomingdales, Marcor, and Sears Roebuck) followed the Japanese, as did European firms such as Marks and Spencer and C&A.

These large buyers were very important to local exporting firms. Buyers often placed orders for 60% to 100% of the annual capacity of exporting firms in sectors such as clothing, electronics and plastics. The large buyers gave many exporting firms in the NICs their first experience in export markets. They also enabled firms to rapidly expand their production capacity and obtain credit on the basis of guaranteed forward orders from the buyers.

Following Hone's work, Wortzel and Wortzel (1981) showed how exporters from the NICs gradually progressed from passively selling low cost production capacity to actively promoting their services to new buyers, to setting up marketing offices locally, and eventually to the direct marketing of products into overseas markets. Firms gradually developed their own in-house marketing expertise and learned about the design of new products, not only in the electronics industry but also in footwear, clothing and other areas. By acquiring marketing skills firms were able to increasingly capture the value-added associated with post-production activities including packaging, distribution, styling and marketing. These post-production activities are often a large component of total value-added.

Foreign buyers not only assisted exporter into export markets but they also supplied technology in various forms. From offices located in Seoul and Taipei, they provided firms with technical information on production and product designs as well as advice on quality. Some buyers even provided help with cost accounting procedures. The largest buyers visited factories frequently and supervised the start-up and running of new operations. Buyers also assisted with the purchase of essential materials, capital goods and components.

2.3.2. Foreign direct investment (FDI)

In electronics the contribution of foreign investment to value-added and production was smaller that of local firms (except for the case of Singapore). In overall terms the contribution of FDI to total capital formation in the four dragons was very small. FDI contributed around 2% to South Korea's total capital formation during the period 1976 to 1987 (James, 1990:11). Over the period 1965 to 1985 in Taiwan FDI accounted for between 1.35% and 4.32% of total capital formation and between 2.5% and 5.47% of private capital formation (Dahlman & Sananikone, 1990:73).

However, FDI was highly significant in sectors such as electronics and machinery. TNCs had the effect of initiating many of the fast growing electronics sub-sectors (e.g. radio production in Hong Kong and Taiwan). Foreign firms often acted as demonstrators for local firms to imitate. TNCs assisted local firms to grow through sub-contracting, OEM and licensing agreements. In some sectors FDI accounted for a significant proportion of manufacturing employment, total employment and exports. For Taiwan, Schive (1990) calculates that FDI accounted for between 9% and 16% of total manufacturing employment between 1979 and 1985, and for roughly 20% of manufacturing exports between 1974 and 1982[17].

Through the TNCs, FDI gave rise to a Schumpeterian process of imitation and swarming on the part of local firms. In some cases the sub-contracting relationships between TNCs and local firms involved technical assistance and engineering support. TNCs constituted an important channel of foreign technology transfer.

17 Part 3 discusses the contribution of TNCs to electronics employment and output in South Korea.

For Singapore, TNCs were the dominant market and technology transfer channel. In Hong Kong TNCs remain very important. In 1989 they accounted for around 112 firms, 32,000 employees (half the total electronics employment) and $1.1bn worth of investment in electronics[18]. In the two larger economies, FDI and joint ventures remain an important conduit for technology transfer, especially the training of local managers and engineers.

2.3.3. Other foreign sources

Other less direct foreign sources of technology included the recruitment of technical staff with experience in foreign firms, foreign education, product copying and reverse engineering of products by local firms. Licensing became more important to firms in South Korea once their technological abilities had reached a fairly sophisticated level. In Taiwan between 1952 and 1988 the Government approved more than 3,000 licensing agreements (mostly in electronics), many including technology transfer clauses (Dahlman & Sananikone, 1990:78). Many local traders were also important sources of technical and market information in Taiwan and Hong Kong.

To sum up, the chief mechanisms by which firms achieved export-led technology development was by exploiting a variety of foreign channels of technology and marketing. Often the channel was dual purpose: both a means of product marketing and a mechanism of technology acquisition. This applied especially to foreign buyers, OEM and joint ventures. However, these events did not occur automatically. They resulted from the efforts, investments and strategies of local firms keen to learn the skills of marketing and technology.

18 Calculated from Fok (1991:259).

3. LATECOMER FIRM STRATEGIES IN ELECTRONICS

Having proposed a scheme for understanding the four NICs' achievements in electronics, this section briefly reviews descriptive evidence on the entry strategies of local firms. The aim is twofold: to partially verify the simple model and to examine the timing of electronics development as firms progressed from electronics production to sophisticated software and research intensive information systems.

3.1. Phase 1 - Industry Start-up (circa late 1959s and 1960s)

The South Korean electronics industry began with the production of vacuum tube radios in the late 1950s. US TNCs established wholly-owned operations in the mid 1960s to assemble simple goods based on cheap labour assembly. US firms imparted little technology to Korean companies according to Bloom (1991:10). In contrast, Japanese firms helped "kick start" local industry. Matsushita and Sanyo provided technical assistance to Samsung and Goldstar in 1961 and 1962 to help set up transistor radio factories. Toshiba, also from Japan, set up a joint venture and began two major technical agreements with local electronics companies in the late 1960s (Bloom, 1991:8).

While Goldstar began in 1958 as a wholly owned local firm, Samsung Electronics began as a joint venture with Sanyo of Japan in 1969. In this year Samsung sent 106 of its employees to Sanyo and NEC for training in production knowhow for radios, television sets and components. Under joint ventures with Sanyo, NEC and Sumitomo of Japan, Samsung was able to absorb foreign technology for a variety of consumer goods and components (Koh, 1992:23). The Samsung venture offered the Japanese firms low cost capacity expansion, cheap labour, low cost management, engineering and overheads, as wages and other costs rose in Japan.

Like South Korea, Taiwan, Singapore and Hong Kong began with simple consumer goods such as transistor radios and black and white televisions in the late 1950s and early 1960s. In 1963 Sanyo formed a joint venture with the Taiwanese importer of its goods, initiating the production of white goods, air conditioning products and audio products. In 1966 Philips (of the Netherlands) set up a plant in the Kaosiung free trade zone in Taiwan to produce resistors, capacitors and simple semiconductor components. In 1970, Philips began producing black and white televisions. RCA, an American firm, began producing memory circuits in 1969 and black and white televisions and monitors for re-export to the US in 1971. Other foreign investors in Taiwan included Sanyo, Matsushita, Orion, Sony, Sharp and Hitachi (of Japan) and General Instrument and Texas Instruments (of the US). Local firms acted as sub-contractors and OEM suppliers to some of these firms. Taiwanese managers, engineers and technicians were trained up within the companies, generating an important human resource for the future.

In Hong Kong, the first firms to enter were Japanese, searching for cheap labour in the late 1950s, mainly producing transistor radios. US firms followed the Japanese. By the mid-1960s almost every major American producer of consumer electronics and semiconductors had goods assembled in Hong Kong. They were attracted not only by low cost labour but also low cost engineering and management. Management and production technology diffused rapidly to local firms during the 1960s and early 1970s. Champagne Engineering Corporation became Hong Kong's first local electronics manufacturer when it began making transistor radios for Sony of Japan in 1959. By 1960 it began producing its own radios, undercutting the Japanese (Henderson, 1989:80). Many other Hong Kong start-ups soon followed suit.

Unlike the other three dragons, Singapore relied almost exclusively on foreign investment. Philips began its commercial activities in Singapore in 1951 with a trading office of four staff. It began making transistor radios in the early-1960s, diversifying into private branch exchanges during the late-1960s. Many other US and Japanese firms entered during the 1970s to make electronics, attracted by the location, the low labour costs and the efficient air and sea ports. Texas Instruments and SGS (of Italy) entered Singapore in 1969 to assemble and test semiconductor components. NEC began producing semiconductors in 1976 (company interviews Singapore, 1992).

To sum up, during the start-up phase, foreign companies were crucial as demonstrators for local firms. They helped initiate the first electronics ventures and began training local engineers and technicians. This in-house experience was to prove a valuable source of foreign technology and management transfer.

3.2. Phase 2 - Take-off, from Assembly to Manufacture of Consumer Goods and Components (circa 1970s)

During the 1970s new product innovations in the West were exploited by latecomer firms in East Asia in combination with foreign TNCs and buyers in search of low cost production. New product lines included colour televisions, digital watches, calculators, push-button telephones and television video games. Some firms mastered the production technology for these goods, although many in South Korea, Taiwan and Hong Kong relied on OEM and buyers for technical assistance and market outlets. In Singapore, the TNCs dominated the scene.

In South Korea several large Japanese TNCs entered during the 1970s (including Sanyo and NEC) with wholly owned subsidiaries. By 1976 around 50% of Korean electronics output was produced in foreign or jointly owned factories, mainly Japanese and American (Bloom, 1991:10). During this phase, the Korean *chaebol* consolidated their links with Japanese electronics producers. Samsung strengthened its connection with Sanyo. Anam, now one of the world's largest semiconductor sub-contract manufacturers, began making colour televisions with Matsushita of Japan in 1973.

During the early 1970s, Samsung and Goldstar acquired technology mainly through technology licensing and OEM arrangements with Japanese firms (Bloom, 1991:10). However, even at this early stage selective in-house R&D was used to help master production and reverse engineer key products. In microwave ovens, a detailed account shows how in 1977 Samsung began a relentless trial and error development effort to master foreign technology. The company undertook a painstaking search to win its first international order (Magaziner & Patinkin, 1989). Samsung is today the world's largest microwave oven producer. In 1977, although there were no television stations in South Korea which could broadcast in colour, Samsung's engineers gathered together colour television sets from GE, RCA and Hitachi, in fact every leading company, in order to help them design their own colour television model for export.

In 1976 Philips began producing colour televisions in its Taiwanese facility in Kaosiung. RCA began to transfer metal oxide semiconductor (MOS) technology to local firms in Taiwan through the government's Industrial Technology Research Centre (interview ITRI, 1992). Sanyo's joint venture began making televisions in Taiwan in 1969 and, later, video cassette recorders. In the early 1970s, IBM began purchasing large quantities of low cost sub-assemblies and simple components from Taiwanese firms. Later in the 1970s new engineering intensive local firms "jumped in" at the (then) state-of-the-art. The best known example is ACER which was established by Stan Shih under the name Multitech International Corporation in 1976, with 11 engineers. By 1987 ACER's sales were $331m. Today ACER has extensive international computer operations and a turnover of more than $1bn per annum (*Electronic Business*, feb. 1993, p. 77).

In Hong Kong, during the mid 1970s successive waves of local firms entered the fast growing consumer electronics industry, often exporting to the US market. By 1982 there were more than

1,200 local electronics firms making calculators, computer parts, digital watches, videogames and other consumer goods. Seventy-seven percent of these were small companies employing less than 50 persons. The electronics industry also gave rise to a large supporting industry in plastic mouldings, metal plating, metal working and parts. By 1991 these firms employed around 30,000 workers in Hong Kong to add to the 64,000 or so employed in electronics factories (Fok, 1991:259-264).

3.3. Phase 3 - Take-off of Professional Electronics, Computers, Peripherals and Start-up of Design and Manufacture of Semiconductors (circa 1980s)

During the late 1970s and 1980s the four dragons consolidated their expertise in manufacturing. In Singapore, process capabilities were acquired within the TNC subsidiaries which dominated the industry. Alongside the improvements in manufacturing capability, more complex design functions were assimilated as domestic firms moved into the production of industrial goods, PCs and peripherals. In the second half of the 1980s, companies increased their competitiveness in high quality precision engineering products such as hard disk drives (especially in Singapore), colour display terminals, video graphic adaptors, television monitors and other computer peripherals. While Taiwan and Hong Kong concentrated on higher value-added niche markets, South Korean firms continued mass producing relatively low end electronic goods.

Early Government policies in Korea had promoted local industry through the Basic Plan for Electronics Industry Promotion (1969 to 1976) and the Electronics Industry Promotion Law (iniciated in 1973). As a result of these policies and the growing strength of local firms, the contribution of foreign firms to exports fell from 76% in 1969 to roughly 55% in 1972 to less than 40% in 1980. Employment in foreign subsidiaries fell by one third between 1976 and 1985, despite the 50% overall increase in employment in electronics (Bloom, 1991:9).

With the rise of Korean firms, Japanese firms withdrew from South Korea. In 1980 Matsushita pulled out of its joint venture with Anam Electric. Sanyo withdrew from its joint venture with Samsung in 1983. NEC withdrew from its venture with Goldstar Electric in 1987. According to Bloom, Japanese firms left for a variety of reasons: the special tax benefits to investors introduced in 1972 were withdrawn; changes in Japanese firms' strategies; and measures taken by the Korean Government to encourage local in favour of foreign investment. However, Korean firms remained weak in semiconductor and other components. Foreign companies were involved directly in about 60% of total production of components within South Korea in the late 1980s. By this time components accounted for some 57% of total FDI in electronics (Bloom, 1991:9).

In Taiwan PCs took off in the 1980s. IBM, Wang and Hitachi purchased large quantities of finished goods and computer sub-assemblies. By the late 1980s, Taiwan's main attraction was low cost high quality engineering, rather than low cost labour. TNCs purchased keyboards, television monitors, printed circuit boards and printers. As in the other three NICs, Taiwanese production shifted to more complex, professional equipment, requiring precision engineering and electro-mechanical interfacing. In Taiwan, the production value of computing and related goods expanded to $6.1bn by 1990, overtaking consumer electronics which stood at $2.29bn in 1990 (O'Connor & Wang, 1992:42 and 54).

In Singapore, as in Taiwan and Hong Kong, consumer goods' technology became more complex during the 1980s, with foreign and local firms making products closer to the introduction phase of the product life cycle. Philips upgraded its Singapore facilities by adding hi-fi audio equipment, colour televisions, compact disc players, and new tuners and precision tools to its product range. By 1991, Philips Singapore employed around 6,100 people in five separate factories and sold more than $800m worth of goods, mostly for export (*Singapore Electronics Manufacturers' Directory*, 1992:76). AT&T began making high end cordless telephones in 1986. By 1990 AT&T's Singapore's consumer electronics division had become its world centre for new product design, utilising automated manufacturing facilities and computerised just-in-time systems for local OEM suppliers (Interview, 1992). Partly as a result of its abundant supply of high quality engineering, by the late 1980s Singapore had become the world's largest supplier of hard disk drives. Competing US and more recently Japanese firms "clustered" together attracting many of the material and technology suppliers to Singapore.

During the 1980s, semiconductor process capabilities were assimilated within foreign and local firms in the region. In 1984 SGS began fabricating semiconductors in Singapore. Since then it has expanded and upgraded its local fabrication facilities to become one of SGS-Thomson's world centres for semiconductor production (Interview, 1992). In 1990 Texas Instruments joined together with Canon (of Japan), Hewlett Packard (US) and Singapore's Economic Development Board to fabricate leading edge (4 and 16 megabit memory) semiconductors in Singapore.

Philips began a joint venture with the Taiwanese Government in 1987 to form the Taiwanese Semiconductor Manufacturing Corporation to make specialist circuits for local design firms. In 1991, Texas Instruments and ACER formed a partnership to produce memory circuits to supply local computer manufacturers. The fast growing demand for microprocessors led Mitac (Taiwan's second largest computer maker) to form an alliance with Intel of the US in 1992 to make the new 80586 central processing chip (*The China Post*, 31 july 1992, p. 9).

To sum up, during the 1980s local firms and their supporting industries grew more technologically capable in several areas of advanced systems production. Foreign semiconductor producers upgraded their production facilities and formed joint ventures with local industry to compete in the rapidly growing markets of East Asia. However, many local firms remained weak in marketing terms. In Taiwan, despite the wide availability of design competence, OEM and foreign companies (including joint ventures) still accounted for a large proportion of total electronics output. In 1989 the six largest foreign OEM buyers in Taiwan were (in order) IBM, Philips, NEC, Epson, Hewlett Packard and NCR (III, 1991:39-43).

3.4. Phase 4 - From Electronics to Information Technology, Software, Advanced Computing and Telecommunications (circa 1990s)

During the 1990s many firms in the four dragons are likely to reach the technology frontier in electronic systems. Further advances will require larger expenditures on R&D, both to assimilated outside technologies and to generate new product innovations quickly. Strategies will focus more on the early introduction phase of the product life cycle, as firms try to become leaders in particular markets. Leading firms will try to make headway into complex applications and systems software for computing and advanced telecommunications. These are areas which the dragons are relatively weak. This strategy, currently underway, will require an upgrading of science and technology facilities both within firms and in the public sector. It can be seen as a push into the higher stages of information technology, based on the dragons strong, cumulative experience in electronics systems production. This strategy is likely to involve more partnership ventures between latecomer firms and the international leaders. Partnerships will enable more Asian companies to acquire further skills, overcome their technological dependencies and build more direct links into advanced markets.

Already, the early 1990s have witnessed the improvement of semiconductor process and design capabilities. Each of the four economies has local, foreign or joint venture firms engaged in the design anad manufacture of the latest semiconductors for use in local systems. Advanced consumer and computer products now originate from within firms in the dragons. Taiwan alone accounts for 10% of the worldwide production of PCs and 22% of notebook computer output (*Far Eastern Economic Review*, 24 sept. 1992, p. 88). As noted above, leading TNCs design and manufacture highly advanced consumer and industrial goods in Singapore, using just-in-time, automated plants.

Some firms have also tried to reduce their dependence on Japanese technology. In South Korea, Daewoo reduced its reliance on Japanese technology from 85% of total procurement in the mid-1980s to 15% in 1992, by forging more links with companies from the US and Europe (*Business Week*, 11 may 1992, p. 26).

Although the four dragons remain weak in marketing and distribution, major South Korean and Taiwanese firms have established marketing departments abroad and are investing large sums in advertising and distribution to gain brand awareness. In 1991 ACER of Taiwan signed contracts directly with mass merchandising outlets in the US, including Best Buy, Circuit City, CompUSA, JC Penny, Bizmart and Staples, to sell its own brand personal computers. ACER plans to begin direct marketing operations in the US in 1993.

South Korean firms have begun to sell own-brand products, some fairly complex ones, including semiconductors, PCs, camcorders, video cassette recorders, compact disc players and colour monitors. Hyundai of South Korea, ranked just below ACER in terms of PC sales into the US, has set up an ambitious marketing programme to double the company's US market share by 1994. To achieve this, it has relocated its entire PC business from South Korea to San Jose and recruited an American ex-IBM executive to run the operation (*Electronic Business*, feb. 1992, p. 61). Nevertheless, with the exception of Singapore, OEM remains a major outlet for exports.

With government help (see Part 4) firms in each of the four NICs are attempting to generate new competitive advantage based on R&D and complex software. As with previous advances, the new skills will add to, rather than displace the dragon's present advantages in low cost precision engineering, high quality design and electromechanical interfacing. The 1990s are likely to witness a rapid accumulation of R&D skills in leading firms, government R&D institutes and the academic sector. Even in Hong Kong a large new University of Science and Technology has been set up to plug the R&D gap.

If these efforts are successful, during the 1990s the dragons will gradually reduce their dependence on Japan and the US fore core technology inputs. They could also make inroads into more complex electronics hardware and begin to tackle advanced computer and communications networking technologies. If the strategy works more local firms will reach the technology frontier and begin to directly exploit the research and science base of R&D institutes to generate new breakthroughs in information technology.

4. GOVERNMENT POLICIES

It would be wrong to convey the impression that NIC firms succeeded in an economic or policy vacuum. On the contrary, government policies of various kinds have had a profound influence on the paths of technological achievement in electronics, as well as emerging patterns of industrial structure and ownership. In addition, policies to secure sound macroeconomic management, favourable exchange rate regimes, high savings, low inflation and low interest rates have created conditions which enabled firms to succeed. In some cases, targeted industry support projects may have assisted firms in climbing up the technology ladder. In general, the development policies followed by the four dragons are well researched and need not be dealt with here. However, it should be noted that serious disagreements exist on the scale, importance and outcome of government industrial policies in each of the four countries[19].

The purpose of this section is to highlight some of the government policies which have proved important to the development of electronics in the four dragons. They include policies toward foreign investment, local industry, education, competition and R&D. It should be stressed that policy mechanisms and outcomes differ in each of the countries.

4.1. Industrial Support Policies, Competition And Industrial Structure

South Korea began its development from a lower base than that of Taiwan and the other dragons. As Levy (1988) shows, market institutions in South Korea were very poorly developed at the outset of industrialisation in the mid 1950s and early 1960s.

19 See for instance Galenson (1985) and Hughes (1987) for interpretations of economic development and government policies in each of the Asian NICs. Wade (1990) looks in detail at Taiwan's Government policies. Amsden (1989) focuses on South Korea's Government policies. Vogel (1991) provides an historical, cultural and political view of how and why the four dragons succeeded.

The response by Government was to support the growth of the large *Chaebol* by procurement, subsidies, market protection and financial incentives (Amsden, 1989). The huge South Korean conglomerates functioned to internalise transactions which might otherwise have evolved in a market setting. By contrast, in Taiwan trading and sub-contracting were relatively well developed. The country began at a higher per capita income level (70% higher than South Korea's in 1955; Levy, 1988:44). As in Hong Kong, there were large numbers of Chinese traders willing and able to exploit new export possibilities. In electronics, development occured among the multitude of small family firms which formed extensive sub-contracting relationships with each other, with local traders and with foreign companies.

As Levy (1988:45) points out, South Korea lacked the indigenous traders and sub-contractors present in Taiwan. Market failure was therefore more prevalent in South Korea. Market institutions were poorly developed and the initial investment cost of entry was that much higher in South Korea. The solution adopted by successive Governments in South Korea was to encourage the growth of large competing oligopolistic firms with sufficient resources to overcome entry barriers. The Japanese *Zaibatsu* provided a nearby role model for South Korea to follow[20].

Government policy therefore had a direct effect on the emergence of the *Chaebol* and the resulting, highly concentrated industrial structure in South Korea (one of the highest worldwide). The South Korean Government employed financial support measures, tax benefits, credits for R&D and training, technology support and procurement of domestically produced goods to help promote the *Chaebol*[21].

Specific actions by the Korean Government in support of a domestic electronics industry included the Electronics Industry Promotion Law of 1973. This law helped set up the black and white

20 There are, however, significant differences in structure, finance and organisation between the South Korean and Japanese conglomerates (Whitley, 1992).

21 For details of Korean Government policies see Lim (1992) especially p. 5.

television industry and encouraged industry to go beyond assembly and acquire technology, to improve ouput quality and to raise exports. As part of the fourth five year plan (1977 to 1981), in addition to the usual incentives, the Government: (i) arranged foreign loans of $221.6mn; (ii) established an industrial estate for the production of computers and semiconductors; (iii) set up the Electronics and Telecommunications Research Institute with a fund of $60m. In 1983 the Government protected the local market against competition in computers and peripherals in other low-end electronics in which Korean firms competed. The Government also restricted FDI in electronics, except for joint ventures. As a result joint ventures were formed by Hyundai, Daewoo, Goldstar and Samsung (Amsden, 1989:83-84).

As in Taiwan, the South Korean Government helped promote export trade through foreign buyers. For instance, in 1962 it created and funded the Korean Trade Promotion Corporation (KOTRA). KOTRA eventually established about 100 trade centres around the world to supply potential foreign buyers with information, contacts, product samples and Korean company information (Rhee et al., 1984:52). KOTRA is situated in the World Trade Centre in Seoul alongside 30 or so private trade associations, including the Korea Electronic Product Exporters Association. These associations track international market developments and supply information to Korean exporters.

In South Korea, competition policies were introduced, not always successfully, to curb the abuse of market power among the *Chaebol*, to stimulate efficiency and to prevent monopolistic practises (Amsden, 1989:130-131). Despite conflicts between the state and the *chaebol*, as Amsden argues, the large conglomerates were the product of a harmony of development interests between Government and private enterprise (p. 136). Rising productivity was stimulated by rapid growth, rivalry among the business leaders and oligopolistic competition (rather than monopoly). The competitive structure was not the result of market forces. On the contrary, market structure and competition were the direct result of the Government's development policy.

Singapore lacked an indigenous industrial base in the 1950s. The Government therefore decided to attract foreign firms as part of its industrialisation strategy. Singapore developed what Vogel (1991:77) calls an administrative state. The Government set up state-owned or controlled enterprises in several key sectors. In electronics it left most decisions to private enterprise. TNCs were attracted by incentives, targeted training schemes, and infrastructural developments in telecommunications and transport. By 1990 more than 3,000 TNCs (including 600 large firms) had set up operations in Singapore. Many of the world's leading electronics companies established manufacturing and headquarter facilities.

The Taiwanese Government also took an active role in electronics, promoting export-led development and taking measures to assist traders and manufacturers to compete in world markets. In 1970 the Government set up the Chinese External Trade Council (CETRA) to carry out market research, to promote packaging and design and to organise trade missions, seminars and trade fairs. By 1989 CETRA had a staff of around 700, including 74 offices in 64 cities in 48 countries (Dahlman & Sananikone, 1990:50). Recently, the Government has promoted technology development through various joint ventures including the Neotech Development Corporation (NDC) and the TSMC (discussed earlier). NDC began in 1983 as a venture between the Government sponsored Institute for Information Industry and IBM to provide exclusive software services to IBM. NDC projects included control boards for the IBM daisy wheel printer and peripherals for banking and retailing computers (Dahlman & Sananikone, 1990:55).

Each dragon followed a different policy path in electronics, leading to sharply contrasting outcomes in terms of foreign ownership and industrial structure. Hong Kong was the only country to follow a *laissez faire* policy. Today it has a mixture of small local firms and large TNCs. Singapore has a concentrated industrial structure based on (mainly) large foreign TNCs. Taiwan has the most dispersed industry structure, relying on small locally owned companies for much of its electronics output. By contract, South Korea has a very concentrated industrial structure based on locally owned firms.

Despite the variety of policies, one common theme among the four countries was the commitment to competition in electronics. Each country prevented the growth of monopolies, curbed unhealthy state-firm relations and promoted export-led competition among electronics firms.

4.2. Education and Training

Another common factor in the success of the four dragons was the emphasis placed on basic education and vocational (especially engineering) training. Private, state, domestic and foreign education all played a part in each country's progress. Many US-trained Chinese engineers and scientists ended up in Taiwan after the second world war. During the late 1970s and 1980s, many of the wealthier families of Taiwan, Singapore and Hong Kong sent their children to universities in the US. South Korean families sent their children overseas to Japan as well as the US and Europe, very often for training in engineering and management (Vogel, 1991:72).

Engineers and engineering training were crucial in each country's development. In Taiwan, engineers helped shape the country's entire economic and industrial strategy. From 1949 to 1985 no less than ten of the fourteen ministers of economic affairs were engineers by training (Vogel, 1991:27). Unlike economists who stressed market forces, Taiwan's engineers believed in government intervention and political and social direction. They set out to ensure technology was acquired and funded large technology intensive projects which could not be justified on a comparative factor cost basis. They took the view that economic development was a direct responsibility of Government.

Under its Ministry of Education, Taiwan invested in engineering training schools, usually located within the major universities. Today, the leading computer and electrical engineering departments are in the National Taiwan University (Taipei), the National Tsing Hua University and National Chiao Tung University (both in Hsinchu). Within the Hsinchu Science-Based Industrial Park alone there are around 8,000 students and faculty. The largest electronics firm, Tatung Corporation, has set up its own university - the Tatung Institute of Technology in Taipei - to train engineers and managers. In 1990 Taiwan's engineering school's supplied about 9,000 graduates with degrees. A further 5,000 obtained degrees in computer science and mathematics. Students obtain a grounding in mathematics, science and basic engineering. Some go on to graduate research supported by the National Science Council (*IEEE Spectrum*, june 1991, p. 61).

At independence nearly one half of all Koreans were illiterate. The country also lacked an adequate supply of managers and engineers (Vogel, 1991:48 and 55). Studies show that Korean industrial development was facilitated by the Government's commitment both generally to education and, more specifically, to the supply of well-trained engineers (Amsden, 1989:238-239).

As noted in Part 1, a large number of engineers are supplied by Singapore's educational institutions and universities. For a long time the Singapore Government has involved large foreign firms in setting up and running its vocational educational institutes. Philips first educational links began in 1971 with a four year craft apprenticeship programme organised with the Ministry of Education. This was specifically designed to increase the supply of human resources in crafts and engineering for Philips. In 1975 the Government's Economic Development Board

(EDB) and Philips set up the EDB-Philips Government Training Centre for precision engineering. By 1991 the EDB operated five joint training institues with an enrollment of 2,500 students: the French Singapore Institute, the German-Singapore Institute, the Japanese-Singapore Institute, the Precision Engineering Institute and the Philips-Government Training Centre. These institutes provide two and three year training courses in tool and die and precision machining, plastics technology, factory automation, mechatronics and industrial electronics.

Engineering courses have become increasingly complex as industry has evolved in the four NICs. In Singapore, in addition to craft and technician programmes, courses now include advanced software training and computing. To encourage TNCs to upgrade to high value-added electronics and R&D, the Singapore Government recently set up the Institute for Manufacturing Technology, the Information Technology Institute, the Institute of Microelectronics and the Magnetics Technology Institute. The advisory boards usually include managers of the TNCs who advise on specific projects and overall direction. In Taiwan and Korea, as in Singapore, the curricula in engineering schools tend to reflect the current and foreseen production needs of industry (e.g. the technology for hard disk drives, PC manufacture, computer printers and software) rather than basic research or science.

Today, the phenomenon of "jumping ship" is well known in Taiwan. This occurs when managers trained up in US corporations return to Taiwan to start up their own firms and research projects. The head of the Government's ITRI, Morris Chang, is well known in the US after a distinguished career in Texas Instruments an GE. Start-up firms such as Microelectronics Technology (established in 1983) retain their links with US corporations including HP, Harris and TRW. The founders of TECOM (established in 1980) originated from Bell Labs and IBM. The directors of Macronix (set up in 1989) were from Intel and VLSI Technology (Interviews at Hsinchu, 1992).

Similarly, the Samsung Advanced Institute of Technology (SAIST), established in 1987, has successfully recruited top level Korean staff, mostly from the US, to direct research into computers, communications, semiconductors and other high technology areas. SAIST has a budget of around $140m per annum and employed around 2,200 staff in 1990. It follows a deliberate strategy of recruiting back Korean engineering and scientific talent from abroad (Interview SAIST, 1991). The popular press in the dragons now speak of the "brain gain", rather than "brain drain", when referring to the pool of local engineering talent in foreign firms abroad.

5. CONCLUSIONS AND POLICY IMPLICATIONS

Considerable care must be taken when trying to draw policy lessons from the experience of the four dragons in electronics. It is not possible to generalise form the case of electronics to other sectors. Nor is it possible to generalise from the experience of the four Asian NICs to other developing countries within Asia or in other regions of the world. Indeed, as shown above, there are considerable difference among the dragons in terms of corporate strategy, government policy, industrial structure, patterns of innovation and industrial ownership. However, some common success factors arise which are worth general consideration and which may have some bearing on the position of other industrialising countries.

In each case technology accumulation in electronics was linked to exports and foreign channels of investment. Foreign buyers and OEM arrangements served a dual purpose. On the one hand they provided an outlet to the international market, assisting firms to overcome market entry barriers (e.g. distribution, packaging, advertising and marketing). On the other hand they served as a direct channel for technology transfer, allowing local firms to gradually learn electronics technology. OEM acted as a "training school" for many local companies. Other important foreign channels included FDI, joint ventures and licensing. Local firms from Taiwan and Hong Kong imitated foreign firms and supplied TNCs under sub-contracting arrangements. These mechanisms were exploited by local firms to bootstrap their way into electronics markets. Korean firms used joint ventures and OEM arrangements to overcome entry barriers and accumulate technology.

For other industrialising coutries, these events show that export orientation and export-led growth was intimately linked to technology assimilation and learning. Local firms in the dragons exploited the various foreign market and technology channels, enabling them to follow and eventually catch up with the world market leaders in electronics. Export-led technology development acted as a focussing device for local firms, guiding investment choices and linking technology investments to the international market.

Under import substitution (IS) policies it is difficult to see how foreign market channels can be used to "pull" technology along in this manner, unless IS is coupled to export-led development as in the case of Taiwan and South Korea. Unless the local market is very large, rapidly growing and sophisticated, local firms under IS may find themselves falling further behind the technology frontier as it advances.

While foreign channels provided the opportunity, local firms were the foundation upon which the dragons developed (with the exception of Singapore). Local firms generated most of the employment, exports and value-added in electronics. Local companies exploited the foreign channels of marketing and technology. Without them, South Korea, Taiwan and Hong Kong would, in all probability, not have succeeded in electronics. Foreign investment was a necessary but insufficient condition for success. The TNCs helped "kick start" local industries, transfer technology and train local technicians, engineers and managers. But local firms forced the pace and scale of progress.

The implication for other countries emerging from IS regimes, is that investment liberalisation alone may not be a sufficient condition for electronics development. The two largest dragons, Taiwan and South Korea, controlled and restricted the inflow of FDI. FDI was used judiciously to assist in the development process. Indeed, FDI only constituted a tiny proportion of total capital formation in these two economies. Therefore, without the exploitation of foreign investment by local companies, liberalisation alone may be insufficient to produce the type of industrial development witnessed in the dragons.

Regarding the process of innovation in electronics, the experience of the dragons may well prove instructive for other countries. Although, there were no rigid "phases" of development, there was a tendency for industry to move from simple assembly to more comnplex tasks involving production engineering, product design, prototype development and R&D. Firms progressed from the mature to the earlier stages of the product life cycle as capabilities were accumulated. Technology was gained in a gradual, path dependent and cumulative manner. Indeed, many firms began in "pre-electronic" activities (e.g. assembly and testing) and gradually moved to the manufacture of simple, then complex electronic systems. Only recently have leading firms entered software intensive information technologies and advanced semiconductors. The path to advanced information technology was a gradual one - and still largely incomplete. For other countries, this suggests that to fully exploit the industrial development potential of electronics, complementary basic industrial and engineering skills are required (e.g. plastic moulding, electromechanical interfacing, precision machining and fine engineering). These skills are needed to produce electronic goods and systems. Their accumulation is also a route towards more complex, higher value-added electronics and information technology.

This "overlap" of technological paradigms has implications for training. It suggest that for electronics and information technology, a strong supply of pre-electronic craft and production engineering skills is needed. Electronics manufacturers in the dragons benefited from government policies which emphasised craft and engineering training in academic institutes and government laboratories connected with industry. One of the key advantages of the NICs is their abundant supply of high quality engineering talent.

Regarding industrial structure and strategy, there was considerable variety among the four dragons. Taiwan relied on a multitude of small, fast moving firms supplying niche markets. Some of these have become fairly large, although they are still tiny by South Korean standards. Hong Kong relied on a mixture of foreign TNCs and small local firms. These experiences suggests that some of the disdvantages of small scale can be overcome in electronics and that there are proven alternatives to the Japanese and South Korean large firm "models" of electronics development.

Competition was more important to electronics success than firm size and industrial concentration. Intense competition for export markets occurred in each of the four NICs. Government policies in each country ensured that competition occurred among electronics suppliers and that monopolisation and collusive practises were curbed. This proved more difficult in South Korea, given the size and influence of the *chaebol*. In Taiwan and Hong Kong the family-based "overseas Chinese" firms tended to promote a climate of competition.

Regarding industrial policy, three of the four dragons (except Hong Kong) practised systematic policy intervention (e.g. tax breaks, subsidies and marketing assistance); South Korea and Taiwan practised import-substitution and FDI restrictions. Singapore subsidised the entry of foreign TNCs. Hong Kong is the only example of a *laissez-faire*, free market approach. The lesson for other countries appears to be that whatever the pattern of industrial structure, FDI, ownership and intervention, strong competition among firms is essential for electronics development.

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