THE DYNAMICS OF HDD INDUSTRY DEVELOPMENT IN SINGAPORE

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Abstract

Singapore accounted for 45-50% of the global shipment of HDD units during the 1986-96 period, making it the single most important location in the world for HDD assembly since the mid-1980s. The continuing concentration of the HDD industry in Singapore comes despite the significant increase in wage and land costs relative to her regional neighbours since the late 1980s. How has Singapore managed to attract and retain such a large share of this industry's manufacturing base? This study discusses the origins of the industry on the island, and how it subsequently grew and transformed. It examines the development of an internationally competitive local supplier base, the government's important influence on the evolution of the HDD industry in Singapore, and how these two groups helped to attract more technologically advanced HDD value chain activities to the island.

1. Introduction: The puzzle of Singapore's dominance in HDD assembly

One of the most remarkable features of the global magnetic hard disk drive (HDD) industry is the high degree of concentration of HDD assembly activities in Singapore. With a total HDD drive production output of S$19.6 billion in 1997 (about US$13 billion), Singapore has been the single most important regional hub for HDD assembly in the world since the mid-1980s. Despite a gradual shift of HDD assembly and related activities away from Singapore to Malaysia, Thailand and China since the late 1980s, Singapore nonetheless still consistently accounted for 45-50% of the global shipment of HDD units over the period of 1986-96, only dipping below 40% in 1997 (Table 1).

McKendrick (1998) has estimated South East Asia's share of the global production of HDD units to be 55.7% in 1990 and 64.2% in 1995. My estimated share of Singapore's are 48.5% and 45% respectively, thus making Singapore's share in South East Asia 87% in 1990 and 70% in 1995.

The concentration of the global HDD assembly industry in Singapore may have peaked in 1997 in light of the slowdown of HDD demand in 1998 leading to retrenchment at Seagate and Western Digital and the closure of Micropolis and Integral Peripherals. The pace of redistribution of HDD supporting industries from Singapore to other parts of Asia had also increased since the early 1990s. However, these de-concentration trends are likely to have been more than made up for by the surge in HDD media production since 1996. Overall, the HDD industry cluster as a whole remains highly concentrated in Singapore, despite rapid changes in its structure and composition since the industry first started in 1981.

The continuing concentration of the HDD industry in Singapore over the last 18 years is all the more remarkable in view of the fact that the Singapore economy has experienced a very significant increase in wage and land costs relative to her regional neighbours since the late 1980s. For example, based on data from the Census of Industrial Production (EDB, v.y.), average wages in nominal prices in the manufacturing industry of Singapore as a whole rose by 7.9% p.a. over 1989-97. Although average wages in the HDD assembly industry in Singapore had risen at a lower rate (5.2% p.a.(per annum) between 1989-97), the HDD industry has had to sustain rapid productivity increases to offset increasing costs; over 1989-97, the HDD industry averaged 11.0% p.a. labour productivity growth in current prices, higher than the 7.9% p.a. for manufacturing as a whole. When one adjusts for the higher rate of price erosion in HDD versus manufacturing goods in general, the productivity growth performance of the HDD industry in constant price would have been even more remarkable. Understanding how the HDD industry in Singapore was able to sustain such high labour productivity growth is an important part to the puzzle of Singapore's continuing dominance in HDD production.

The aim of this study is to explain Singapore's rise to dominance in HDD assembly by tracing how the industry first started on the island, and how it subsequently grew and transformed. Our analysis will highlight the growing linkages that the industry has created between Singapore and her regional neighbours, thus positioning Singapore as a regional production and logistics hub for the HDD industry, and for the electronics industry more generally.

Second, we will examine the extent to which the HDD industry stimulated the development of an internationally competitive local supplier, including precision engineering, printed circuit board assembly, automation equipment design and other manufacturing process engineering services. We will also highlight how the industry has helped train a large pool of skilled managers, engineers, technicians and operators in managing, engineering and operating advanced manufacturing processes. These personnel would later be able to move into even higher value-added industries like semiconductor wafer fabrication and assembly of other advanced miniaturized precision devices. In sum, we will examine how the industry contributed to the development of local capacity.

A third aim of the study is to show how the development of such local engineering capabilities and supporting industry know-how not only reinforced Singapore's competitiveness as an HDD assembly hub, but also, in conjunction with active government promotion policy, helped attract more technologically advanced HDD value chain activities to Singapore: Disk media manufacturing and their associated fine chemicals manufacturing, flex-circuit manufacturing, and even HDD drive design and associated chip design services and R&D activities. Although the latter has not yet happened on a significant scale, our analysis suggests that Singapore has already established a strong foundation to build new competencies that are further up the value chain of HDD activities, as well as in other related industries like optical storage and IC chip design activities.

Last, but not least, we argue that the historical development of the HDD assembly industry in Singapore (and consequently the whole of Southeast Asia) cannot be explained on the basis of natural market forces alone -- the visible hands of the government in shaping that dynamic must be counted as well. While corporate locational behaviour is influenced by complex considerations of agglomeration economies, path dependencies arising from sunk costs, managerial inertia and relationship-specific transaction costs, operational strategy, organizational capabilities, herd instinct and other forms of bounded rationality of managerial decision making, our analysis of the HDD industry development in Singapore suggests that some of these factors can be shaped and influenced by the host country's policies.

2. Historical Development of HDD-related activities in Singapore

2.1 Overview of HDD-related activities in Singapore

Compared to other locations in South East Asia, Singapore was the first to be picked for any HDD-related manufacturing operations: that of heads sub-assembly. Singapore quickly graduated to assembly of complete drives, and rapidly grew to become the leading location in the world for drive assembly over the years. As can be seen from Table 1, Singapore's share of global shipment volume of HDDs hovered around 45-50 % for most of 1986-96 (reaching a peak of 63% in 1990), before declining to 36% in 1998. However, because Singapore produces the higher end drives compared to the rest of the region, her share in terms of value is likely to be higher than 36% in 1998.

Table 2 shows the rapid growth of HDD production in Singapore over 1987-97. As can be seen, output value grew nearly six-fold from S$3.4 billions in 1987 to S$19.6 billions in 1997, while employment increased from 12,500 to 36,300. In terms of exports, the number of disk drives shipped from Singapore-based HDD makers increased from 3.8 million units in 1986 to 52.2 million units in 1998, or an average compound growth rate of over 24% p.a. (Table 3).

The dominant position of Singapore as a regional hub for HDD assembly can be seen not just in terms of her share of global HDD output, but also from the fact that every major HDD maker in the world, with the interesting exception of a number of Japanese majors, has established its most significant and/or most advanced assembly operation in Singapore. Table 4 shows the historical time-line of HDD manufacturing investment in Singapore since the industry first started in 1981, while Table 5 shows the scale of operations of the major HDD makers in Singapore as of 1995. Also remarkable is that practically all HDD majors that have ever established operations in Singapore have continued their operations there for as long as the company's life span; there is only one known case of an HDD manufacturer exiting Singapore entirely to relocate to another location--Syquest.

The growth of drive assembly activities has stimulated the co-evolution of a wide range of supporting industry activities being carried out in Singapore: printed circuit board (PCB) making and PCB assembly (PCBA) operations, die casting, metal stamping, precision machining and plating of various mechanical components such as baseplates, cover and actuator arms, connectors and automation and clean room design services. Table 6 shows the representative leading firms in the various major supporting industries that have emerged in Singapore. Some of these activities had subsequently moved offshore in later years (see section 3 later), but their presence in Singapore has remained strong to this day. Since the mid-1990s, Singapore has also emerged as a major location for disk media chemicals and sputtering activities. By 1997, four major disk media companies had established operations in Singapore -- Hoya, Seagate Media, Stormedia and Mitsubishi Chemicals. (Stormedia has since exited the industry in 1998.) Singapore has also attracted a number of other significant component suppliers - e.g. Adaptec in manufacturing of connectors, Nidec in drive motor manufacturing, and FerroTec (Japan) in sealants.

With the establishment of the Data Storage Institute (known earlier as the Magnetic Technology Centre) by the Singapore government in 1992 to conduct a range of R&D activities related to magnetic storage and the beginning of some drive design activities by a number of the HDD companies in the second half of the 1990s, Singapore is beginning to extend her involvement in the product innovation stages of the HDD value chain as well. In what follows, we trace in greater detail the development of each of these key value chain activities in Singapore over time.

2.2 How It All Began…

The first assembly operation of data storage products in Singapore were for floppy drives. This was established by Micro Peripherals in Singapore in 1981 and Tandon shortly thereafter, but both were short-lived. The first HDD assembly operation was started one year later, in 1982, by Seagate, three years after the company was founded in the US. Interviews with a number of industry informants suggest that Mr.Tom Mitchell, director of operations for Seagate at that time, was primarily responsible for the decision to start component sourcing and later drive assembly in Singapore. According to Mitchell, Seagate decided to relocate component production and eventually entire drive assembly from Santa Cruz due to the "high cost, marginal quality and poor availability of labour" there.

The decision to relocate to Asia was narrowed down to three places: Korea, Hong Kong and Singapore. Singapore was chosen for a number of reasons: the immediate availability of relevantly-skilled labour from a floppy disk drive manufacturer (Tandon) that just closed down its operation in Singapore; a quick and generous offer of investment incentives by EDB, the government investment promotion agency in Singapore; the general availability of well-trained, English speaking workers and engineers; and the presence of US-trained, experienced engineers who were able to manage the start-up of production on short notice and with little supervision. It is important to note that Mitchell was once the procurement manager for Fairchild, and in that capacity had developed a thorough knowledge of the manufacturing capabilities of countries in Asia. Mitchell contrasted the experience he had in Hong Kong with respect to Singapore: "I did not feel that the infrastructure was there in Hong Kong to help a small company like ours. In contrast, we were received by EDB officers at the airport, and they took us to see all kinds of manufacturing plants and to talk to the CEOs of these companies."

S.C. Tien, a Singaporean engineer who had worked in the US for IBM, responded to a small advertisement put up by Mitchell to recruit a manager who could procure parts and components for the disk drive industry. Mitchell was sufficiently impressed with Tien at the interview that he offered to try him out to start a head sub-assembly operation in Singapore. Through contact with the EDB, Mitchell was able to locate a local mechanical and electrical (M&E) engineering consulting firm that was helped Seagate quickly re-design and retrofit an existing factory vacated by NEC for the new sub-assembly operation. The operation then expanded to include printed circuit board assembly (PCBA) as well. Mitchell reported cost savings of 20% on components when he started procurement in Singapore.

The quick start-up and subsequent good performance of the sub-assembly operation instilled Mitchell with confidence in Tien. So in late 1982, when Seagate was under pressure by IBM to promise volume delivery before end of 1983, Mitchell made the decision to start drive assembly in Singapore. He reportedly told Tien, "if we fail, there will be no company left". Tien proposed to Mitchell to move the labour-intensive heads sub-assembly operation to another cheaper location outside Singapore, while commencing final drive assembly in Singapore to meet the cost target of IBM. Thailand was proposed as the site in view of her abundant supply of cheap labour. But more importantly, Tien knew of someone who could be relied upon to manage the new start-up quickly: his own brother, SG Tien, who was working for an American MNC in Bangkok at the time. (Mitchell had earlier preferred the Philippines, but may have changed his mind when the Philippines

Board of Investment made him wait one hour. Malaysia was ruled out when the Malaysian Industrial Development Authority (MIDA) wanted them to go to the East Coast of Peninsular Malaysia.) The transfer of operation to Thailand was so well-managed that the sub-assembly operation in Singapore reportedly stopped on a Saturday afternoon and the same operation was started in Thailand the next Monday morning, with virtually no interruption of production output.

The success of the move to final assembly operation in Singapore exceeded headquarters' expectations. Besides the managerial leadership of Tien, three factors in the Singapore industrial environment proved to be important. Firstly, in the initial start-up stage, Tien was able to recruit a fair number of workers who already had some familiarity and experience with the assembly operations of floppy disk drives in Tandon, which ceased operations shortly before the start of Seagate's drive assembly operation. This experience made the initial start-up easier.

Secondly, Tien built a strong senior management team by recruiting a number of friends who had relevant experience and expertise. Among these were Mr. Gomez, who had worked for several years as an accountant in General Electric Singapore, and Dr. Joe Chen, a lecturer at the electronics engineering school at the National University of Singapore; they became the financial controller and engineering director respectively of Seagate operations. Chen in turn later brought in a number of his former engineering students.

Thirdly, to reduce the cost of final assembly, Tien, with the help of EDB, searched for a number of local entrepreneurs who could start making metal parts and components for the disk drive: baseplates, covers, surface treatment. The timing of this search for local supply of parts and components was fortuitous in that, one year earlier, a German subsidiary firm making cameras in Singapore, called Rollei, had ceased operation. The firm had built up over the years a significant pool of experienced precision engineering technicians. After losing their jobs in Rollei, some of these technicians set up their own precision tool and die operations in the hope of servicing the new electronics MNCs that were beginning to invest in Singapore. These local suppliers proved capable of making precision parts and components to the satisfaction of Seagate.

2.3 The First Waves of "Follow-the-Leader" Moves by other HDD assemblers (1983-88)

The success of Seagate in establishing drive assembly in Singapore apparently did not go unnoticed by her competitors in the US. As a result, Seagate's move to Singapore was quickly followed by other major investments by several leading competitors of Seagate from the US, including Maxtor, Miniscribe, Microscience and CDC (known later as Imprimis) during 1983-4. A second wave of major new HDD investments came to Singapore shortly after the 1985 recession: Micropolis, Conner, Rodime (from Scotland), and Western Digital (see Table 4).

Why did these firms choose to follow Seagate into Singapore? Our interviews with a number of key executives and industry consultants who were involved in the starting up of some of these new majors suggested a "follow-the-leader" behaviour. For example, Mr. H.B. Chan, who was recruited by Finis Conner to head up the Conner operation in Singapore, recalled the following: "Many disk drive manufacturers had already set up here by the early 1980s. Finis Conner thought there must be a reason for it." After an investigative trip, Mr. Conner was convinced of locating his

new plant in Singapore because of the proven track record of Singapore managers, engineers and workers in HDD assembly. Similar reasons were given by two former Maxtor managers and a consultant in clean-room design for Western Digital.

The decision by Conner to recruit a local man, Mr. H.B. Chan, to head up the new operation in Singapore is an interesting illustration of the "proven track record" argument. Prior to his appointment by Conner, Mr. Chan worked for Fairchild in Singapore in 1975, and subsequently established a reputation for helping American electronics MNCs start-up their operations in Singapore and the region in a very short period: National Micronetics in Philippines in 1979 and in Singapore in 1982, Sunward in Singapore, Malaysia and Philippines and Printronics in 1984. This ability was deemed of particular importance to Conner, who wanted to ramp up their production of the company's new 20MB 3.5" drive in Singapore as fast as possible to get their products to market early. Interestingly, Mr. Conner was introduced to Mr. Chan by three different sources: the Economic Development Board (EDB) senior officers whom he went to see to seek pioneer status tax incentives, a former head of Micronetics he knew, and Tom Mitchell, who happened to know of Chan when he was in Fairchild Singapore and later in Micronetics which supplied heads to Seagate.

Besides helping Conner to get EDB approval for the Pioneer Status tax incentive in a very short period, Chan was able to get the Conner operation in Singapore to start volume production within 3 months. He did so, remarkably, without poaching any staff from Seagate Singapore. Instead, he hired engineers/technicians he knew through his previous companies as well as some new ones and sent them to Conner's San Jose plant for training. These engineers were largely responsible for managing the equipment transfer and proposing changes to the factory layout to improve the manufacturing process flow. According to Chan, by 1989, or within two years of the operation's beginning, the Singapore plant of Conner was producing close to 80% of Conner's global output value, way beyond the original expectation of Conner.

As a testimony to the capabilities of Chan and his local Singaporean engineers, Finis Conner asked Chan to transplant the Singapore operation to Scotland "lock, stock and barrel," in 1990. According to Chan, he sent key Singaporean engineers to Scotland to oversee the factory building, while asking teams of Scottish engineers and technicians to be sent to Singapore for training. The Scottish plant was up and running within three months.

While initially relying on supplies of parts and components from the US and elsewhere, Chan played a key role in stimulating the development of local supporting industry by actively pursuing a local vendor development program. Unlike Seagate, which became more vertically integrated over the years, Conner Singapore pursued an aggressive outsourcing strategy. Chan helped the growth of fledgling local precision engineering firms like CAM-Mechatronics and Uraco by giving them jobs for baseplates and covers. He gave a major boost to the development of the contract manufacturing industry in Singapore by outsourcing major PCBA businesses to Tri-M, Natsteel Electronics and SCI. He helped convince Elek and Eltek, a major PCB supplier based in Hong Kong, to establish a manufacturing plant in Singapore, and similarly persuaded Nidec to commence spindle motor production in Batam (Indonesia). He also cultivated the development of local clean-room M&E design know-how by giving a local firm (Perdana Consulting) major plant expansion contracts.

Although not at the same scale as Conner, other HDD assembly investments that came during the period of 1984-89 achieved similarly fast ramp up of production because of the ready availability of technical skills, minimal red-tape in starting up facilities, investment incentives, and increasingly good supporting infrastructure, including the growing number of local suppliers. For example, Rodime, a Scottish company that pioneered the 3.5 inch drive format, came to Singapore in 1987 after a disappointing experience in trying to start drive production in Boca Raton, Florida (close to IBM's PC plant). Rodime recruited as the first managing director of their plant in Singapore a former manager with Tandon Singapore, which closed its HDD facility in 1987. He in turn brought in several senior engineers from the Tandon plant. Rodime was able to ramp up production fast by readily securing HSA, PCBA and baseplates from suppliers in Singapore.

When Rodime subsequently went out of business in 1991, its manufacturing plant and some drive designs were brought over by Myrica, a Taiwanese firm. Again, Myrica was able to ramp up production quickly by employing the key managers and engineers from the now defunct Rodime. (Myrica later failed and exited the industry in 1993.)

Miniscribe's investment in Singapore in 1984 was headed by an American, Jim Steger, rather than a local. But he was also able to start up production fast by leasing a ready-made facility from the Jurong Town Council (JTC) (a government statutory board responsible for developing industrial land for leasing/sales to manufacturing companies) through the help of EDB, and hiring a local HR manager who had experience in the industry and hence was able to poach engineers from existing plants. Western Digital's start-up in Singapore in 1988 was similarly headed by an expatriate from the US, and he too was able to start up operation quickly by acquiring an existing facility that used to belong to Tandon and recruiting experienced engineers from Seagate.

CDC entered into HDD assembly activities in Singapore via a somewhat different route. CDC had originally started a regional sales operation in Singapore for supercomputers in early 1982. The operation later diversified into the sales of storage media and HDD. Sensing the rise of OEM sales of disk drives to emerging Asian PC makers such as Acer, Mitac and Samsung, CDC decided in 1987 to establish its first overseas HDD assembly operation in Asia to be close to these Asian customers. According to Mr. Andrew Ng, the Singaporean regional sales manager for CDC at the time who was involved in the feasibility study for plant location, the final choice came down to either Korea and Singapore. Two factors helped tip the balance in favour of Singapore: first, the Korean wanted a joint venture arrangement, whereas the EDB in Singapore welcomed 100% CDC ownership and offered tax incentives; and second, Singapore already had a good supplier base and "ready made" factory sites that could support fast production ramp up. The head of CDC was reportedly told by EDB that production could start up "as fast as you can ship your production equipment in". It also helped that EDB was well briefed on CDC's interest ahead of time by Ng and was able to make a good promotion pitch, including lining up competent local suppliers who could work with CDC immediately.

Illustrative of the contribution of local expertise, Ng played a key role in managing the production transfer from the US to Singapore, including identifying suitable local managers with HDD experience to staff the startup. Ng was subsequently appointed managing director of the assembly operation after Seagate bought CDC in 1988. In that capacity, Ng was able to leverage his previous regional sales experience to "teach the Americans how to do OEM business in Asia".

Ng used his Asian business knowledge to systematically cultivate the then small but promising Asian PC makers like Acer and Mitac (Taiwan) and Legend (China), which later grew to become major OEM customers of Seagate. In the process, Ng had to impress on Seagate the importance of dealing with these Asian companies in their own terms (e.g. in the earlier years, Asian companies like Acer insisted on Japanese-style "verbal" contracts rather than elabourate legal contracts). The decision by the heads division to subsequently locate a new thin film head plant in Penang, Malaysia was also made by a US manager who had been intimately involved in the earlier setting up of the Singapore operation.

2.3 The Third Wave of HDD assembly operations (1994-1996)

Despite rapidly rising costs in Singapore, new HDD investments in Singapore continued through the late 1980s and early 1990s in the form of aggressive expansion of facilities by most of the existing big players as well as new start-ups by a number of smaller players like PrarieTek, Myrica, Integral Peripherals, Ministor and Syquest. Some of these start-ups were by senior executives from existing HDD majors, for example Integral Peripherals was co-founded by a senior manager from Seagate, while Ministor also attracted a number of senior people from existing HDD makers. More significantly, in 1994, both IBM and Matsushita Kotobuki Electronics (MKE), the manufacturing partner of Quantum, also decided to start HDD assembly operations in Singapore. In 1996, Seagate decided to acquire Conner, but chose to continue its assembly and media operations in Singapore. Western Digital similarly went on an aggressive expansion plan in Singapore to make high end drives, despite having made earlier investments in Malaysia. Even Maxtor, which was acquired by Hyundai in 1994 and for a time was rumored to be downsizing and relocating to Korea, subsequently decided to close its Korean facility instead and concentrated its expansion plan in Singapore. All these new investments/expansions from about 1994 can be seen as constituting a third major wave of HDD development in Singapore.

By 1996, therefore, every one of the six largest HDD companies in the world had established a significant manufacturing presence in Singapore. Besides the newcomers IBM and MKE, the other four HDD majors have significantly expanded their HDD assembly operations in Singapore over the years, even though they all have redistributed the assembly of lower-end products or lower value-added sub-assembly operations to other countries in the region, including Thailand (Seagate), Malaysia (WD, Conner and Maxtor), China (Conner), and the Philippines (Seagate). As can be seen from Table 7, between 1990 and 1995, there was no aggregate reduction in HDD assembly employment in Singapore in spite of the redistribution to regional neighbours.

The dominance of Singapore as a location for HDD assembly was particularly striking for US companies. By 1996, with the exception of HP, every one of the eight largest major American HDD producers had located production facilities in Singapore. (HP had since decided to exit the HDD business.) As can be seen from Table 5, the Singapore assembly operations of the top 6 US HDD makers accounted for more than one-third of the world-wide employment of these companies. Indeed, Seagate had been the largest single manufacturing employer in Singapore with 15,000 employees, even before its acquisition of Conner. It is also interesting to note that while some of the companies that started HDD operations had since been taken over by competitors or exited from the business entirely (e.g. Rodime exited in 1991, Imprimis was acquired by Seagate in 1989, and

Microscience and Myrica from Taiwan exited in 1993 and 1994 respectively), none of the surviving players that started operations in Singapore (with the exception of Syquest) had relocated entire manufacturing operations out of Singapore.

Why did the HDD companies not move out of Singapore entirely? And why do late entrants into South East Asia like IBM and MKE still choose Singapore rather than other countries? The decisions by IBM and MKE to move into Singapore, despite the already high cost of Singapore and the rise of strong regional competition from Malaysia, are particularly instructive. Indeed, the decision by IBM to invest in Singapore was considered quite a coup by EDB, as it was rumored that EDB had tried to get IBM to invest in Singapore for 15 years without success, and the IBM Data Storage group had not started any new plant outside the US for 5 years prior to the investment in Singapore.

IBM considered several factors and various alternative locations, including Thailand where they had subcontracting arrangements (managed by the IBM Japan office) since 1988. However, a number of senior IBM managers in Singapore had suggested that, besides political stability, the higher level of technical expertise and infrastructure as well as logistics infrastructure in Singapore were key factors. Another major factor appears to have been the ability to ramp up production in a very short period in the new location. To the extent that this is true, the decision to invest in Singapore was vindicated in that IBM Singapore was able to achieve ramp up to volume production within a very short period. The company moved into a facility leased from JTC on Oct. 4, 1994, shipped its first drives to San Jose for qualification on Oct.15th, and began production ramp up in early 1995. The plant was fully operational before the middle of 1995. According to Chan, such speedy production transfer was something practically unheard of in IBM experience. By early 1995, part of IBM's drive assembly operation in Germany was transferred to Singapore as well (the rest went to Hungary).

Facilitation by the Singapore government certainly helped in quickly making available industrial space within an existing industrial park. But a more important factor for the rapid ramp up was the fact that IBM recruited a very experienced local man to head up the startup operation in Singapore: The same H.B. Chan who had previously headed Conner's startup in Singapore. By June 1993, Chan had decided to leave Conner when the Singapore operation came under the supervision of Tom Mitchell who was brought in from Seagate by Finis Conner as VP of Operations. In starting up IBM's operation, Chan was able to lure away key local executives from existing HDD majors to help him; all ten of his most senior managers had previously worked for him at Conner at one time or another. Another 30-40 second line engineers were reportedly former Conner employees as well. Chan claimed that the experienced team he was able to assemble was the key reason for his ability to manage the fast transfer and ramp-up. Another facilitating factor was the fact that he was given a relatively freer hand in the initial period, which enabled him to activate some of the local/regional procurement networks he had built up over the years to ensure smooth supplies of key parts and components in a very short time. For example, Chan was able to get Natsteel Electronics, a local contract manufacturer, to ramp up PCBA in support of IBM on short notice. (Chan later left IBM Singapore, citing as one reason increasing control by IBM over what suppliers he can deal with, and restrictive conditions on qualifying suppliers.)

In the case of MKE, press reports suggested that the main reason cited by MKE management for choosing Singapore was the availability of technical skills to implement the highly automated process lines that MKE was known for. Interviews with senior EDB officers suggested that MKE had similarly been pleased with the speed with which they could ramp up production in Singapore. Indeed, MKE told EDB that their Singapore operation achieved parity in productivity and quality with its lead manufacturing plant in Japan within one year of starting up in Singapore. The ability of the Singaporean engineers and workers to master the highly automated process technology was cited as a major contributing factor.

While IBM and MKE were moving in, nearly all the existing HDD majors in Singapore redistributed some drive assembly activities to other countries. Conner redistributed production to Penang, Malaysia in 1989, two years after starting up in Singapore (Haggard, Li and Ong 1998). This was followed by the move to Scotland in 1990 and Shenzhen, China in 1991/2. Seagate shifted drive assembly to Thailand in 1987. WD redistributed to KL, Malaysia in 1994, and Maxtor moved some subassembly activities to Thailand in 1995.

Despite such moves, however, the Singapore drive assembly operations of these HDD majors remained significant and were often upgraded as lower-end activities were moved out. As can be seen from Table 7, the reduction in the headcount of several of the existing majors were made up for by the new investments from IBM and MKE.

It is interesting to note the role played by senior Singaporean managers and engineers in the redistribution of drive assembly activities from Singapore. The case of Conner is most illustrative because of the influential role that the local managing director of Singapore, Mr. H.B. Chan had played in not only extending the HDD industry growth to Penang, Malaysia, but also in helping to build up the local supporting industry there. Facing labour shortage problems in Singapore and looking for opportunities to reduce costs, Chan actively scoured for an alternative location outside Singapore for Conner's next drive assembly operation expansion. He chose Penang and convinced the Conner corporate headquarter to go along. The choice was made based on a number of criteria: proximity to Singapore, availability of labour and engineering skills, and good command of English language at the level of managers, engineers and technicians. It helped that the Chief Minister of Penang was very supportive and facilitated Pioneer Status tax incentives from MIDA within a few months.

In ensuring a fast and smooth start up of Conner's Penang operation, Chan got practically all his key supporting industry partners in Singapore to go with him to Penang – CAM, Tri-M, Natsteel Electronics and MMI established operations there. Although initially to supply Conner's Penang operations, all these supporting industry firms eventually ended up supplying part of Conner's Singapore operation from Penang as well. Chan also brought along the Singaporean M&E engineering firm he had worked with earlier to design the clean room production facility in Penang. According to Chan, the strong reliance on Singaporean suppliers was necessitated by the fact that little local supporting industry capabilities existed in Penang at the time, and Conner needed to ramp up production fast.

Chan did stimulate the development of local engineering expertise as well as the growth of a number of local Penang firms subsequently. In starting up Conner Pennag, he sent only one senior

manager from Singapore to head up the Penang operation as plant manager, but mainly used engineers and managers recruited from the many semiconductor manufacturing factories around the Penang area. To stimulate the development of local supporting firms, he got Conner Penang to support a new local PCBA supplier firm (TransCapital) co-founded by an ex-Conner Penang employee, a Malaysian engineer who had earlier worked in Conner Singapore.

After setting up new transplants in Penang and Scotland, Chan was also responsible for setting up Conner's assembly plant in Shenzhen, China in 1991/2. Again, Chan relied on the same method of using his experienced Singaporean managers and engineers to help supervise the transfer and training process.

In all three cases of redistribution from Singapore, Conner initially used the Singapore operation as a "transfer station". Basically, new drives were first sent to Singapore for ramp up. After the Singapore plant had tooled up the assembly process lines for the new drive products and achieved process stability for volume production, the drives were then sent to be assembled in the other plants, which also received technical support by Singapore process engineers in terms of tooling design and equipment transfer. Over time, however, Conner shifted to a direct ramp up strategy from the US, whereby the different assembly plants were given responsibilities to handle different families of drives, and the new drive designs in each family were sent directly to the designated plant for ramp up. Under this new system, the Singapore plant took on the higher-end drives responsibilities.

The expansion of Seagate's drive assembly activity to Thailand also involved a significant transfer station role for the Singapore plant in the initial years. The Thailand plant started by taking over responsibilities of assemblying the older, more mature products, with some of the process equipment being transferred from the Singapore plant itself. The Singapore plant was also the first to invest in automating specific production stages, and after these new engineering changes were stabilized, the tooling designs were then transferred to the Thailand plant. With the acquisition of Conner, however, Seagate also adopted the Conner practice of segmenting the Singapore and Thai operations by product families and doing direct drive transfers from the US.

The expansion of Western Digital's drive assembly activities to Kuala Lumpur, Malaysia was also managed out of Singapore, and the Singapore-based managers and engineers were significantly involved in overseeing the transfer of technology and management system to the K.L. plants. The same Singaporean clean room design consultant was used to commission the plant in Malaysia. Indeed, a senior Western Digital manager in the Singapore plant remarked that the first Kuala Lumpur plant was an identical duplicate of the Singapore plant: "you cannot tell them apart." Like Conner, Western Digital also used the Singapore operation as a "transfer station" for the drive operation in Malaysia in the start up phase of the latter, but unlike Conner, Western Digital continued the same practice up to 1999, with manufacturing process development responsibility residing largely in Singapore.

2.4 HDD Assembly Consolidation, Growth of Disk Media Cluster and Emergence of Drive Design Capabilities (1997-99)

While drive assembly activities appear to have reached a plateau by around 1998 and may have started to decline after that (with retrenchment at Seagate and WD, and the exit of Micropolis and Integral Peripherals in 1998), a new related industry has rapidly emerged to make up for the slackening of drive assembly activities: disk media manufacturing. The disk media sputtering industry has expanded rapidly over the period of 1995-97, rising from a negligible share of the world total shipment in 1995, to 9.5% in 1996, and 20.7% in 1997, making Singapore among the leading locations for disk media production in the world. Except for Komag, IBM and Hitachi, the other three major disk media producers had all established production facilities in Singapore – Stormedia, Seagate and Hoya. (Stormedia has since exited the industry). Mitsubishi Chemical Infonics had also invested a major production facility in Singapore to produce disk media in 1997, two years after initiating manufacturing of CD-R drives in Singapore.

There is no doubt that this growth in the disk media industry has been very much targeted by EDB as a way to strengthen Singapore's regional hub role in HDD. It is unclear, however, how much of the growth of the industry has been facilitated by government tax incentives, and how much of it is due to the changing economic imperatives for disk media operations to be close to high end disk assembly operation, where yield is relatively low and close interaction between media suppliers and the drive assemblers may be necessary to facilitate failure analysis. Stormedia reportedly decided to locate in Singapore because it was convinced of the importance of proximity to customers (Seagate, Micropolis). Recognizing that only part of the disk media manufacturing process is of high value added, the Singapore government had sought to encourage disk media firms to invest primarily in the chemical production stage and the disk sputtering stage in Singapore, but not in the disk stamping and polishing stages, which are low in value added and rather land and water intensive. One industry informant suggested that Singapore may have lost a Japanese disk media investment to Philippines because the company wanted to have all the media production stages in one site, which the EDB was reluctant to approve.

Besides the development of disk media production, the Singapore government also actively sought to promote a diversification of the HDD industry into optical storage, and to promote the development of drive design capabilities and HDD-related R&D investments. By 1998, Singapore had attracted several major CDROM production investments, including Mitsubishi Chemical Ionics, Summit, Eastgate, and Optics Storage. Except for Mitsubishi, the latter three were local companies. Interestingly, Optics Storage was founded with the backing of H.B. Chan after he left IBM.

In 1992, the Singapore government invested in a new public R&D centre called the Magnetic Technology Centre (MTC) to develop indigenous technological capabilities and to provide support for possible R&D activities by HDD majors in Singapore. Few R&D activities by the HDD majors were actually forthcoming in the initial years, despite R&D incentives and the effort of MTC. The government nonetheless continued to pour resources into MTC, and in 1996 upgraded the centre into a larger R&D institute called Data Storage Institute (DSI), with a broader mandate to cover R&D in not only magnetic recording technology, but also other data storage technologies, especially optical storage technologies. DSI's staff strength rose to 144 by 1998, with an annual budget of about S$28 million.

After some false starts, Singapore's efforts to acquire HDD product technologies and drive design capabilities appear to be finally bearing fruit in the late 1990s. After some initial fumbling, DSI gradually began to build some strong core competencies in selected technology areas. This has enabled DSI to attract a growing number of major data storage technology companies to enter into R&D collabouration with DSI. For example, DSI established the Multilevel Decision Feedback Equalization (MDFE) Consortium in 1997 with the participation of six leading MNCs (Hitachi, Fujitsu, IBM, Silicon Systems, Motorola and Tektronix) and one local company (Serial Systems). In 1998, another consortium was established on phase change media for DVD-RAM applications involving three MNCs, three local firms, and the Productivity and Standards Board (PSB). As of 1998, DSI had three approved patents and 17 pending, and had spun off one company in laser texturing of magnetic discs and laser micro-fabrication.

In terms of acquiring drive design capabilities, an ill-fated attempt was made by the Singapore Technology (ST) Group, a large high-tech conglomerate group owned by the Singapore government, to acquire Micropolis in 1996 when the latter was running into financial difficulties. Although the government emphasized that it was a commercial decision made by the ST Group to attempt to break into the global HDD industry, some observers saw the acquisition as at least partly motivated by the Singapore government's interest in having a Singapore-owned company acquiring significant HDD drive innovation capabilities. The acquisition proved to be a financial disaster, as Micropolis's competitive position further weakened after the acquisition, and eventually had to be liquidated in 1998. Although the amount of investment by ST in Micropolis was not disclosed, it was rumored to be several hundred millions of Singapore dollars.

Notwithstanding this setback, Singapore's efforts to encourage the HDD majors to invest in drive design activities in Singapore through the granting of R&D incentives to HDD majors did eventually bear some fruit. Seagate Singapore first embarked on deepening her "continuation engineering" activities in Singapore into a drive design centre in 1992 through the support of the Singapore government in the form of direct R&D grants. However, the initial design effort was not of acceptable quality, and no major volume production resulted. Undaunted, the Singapore government continued to provide direct R&D grants to support Seagate Singapore's investment in local drive design capabilities. By 1997, R&D staff at Seagate grew to a strength of 140. Seagate's R&D investment effort finally led to the successful introduction of a new low-cost drive ("U4") that began volume production in early 1999. Meanwhile, Western Digital Singapore also made some head way in chip designs, resulting in some new drives incorporating Singapore-designed chips into their new drives. In terms of process development capability, the Singapore managers at IBM, Seagate and Western Digital all reported a significant rise in local tooling design responsibilities and local process innovation capabilities. IBM, for example, reported up to 80% of tooling and test equipment being sourced locally in mid-1997 (IBM Interview). IBM had also established an advanced failure analysis labouratory and a regional technical support centre in Singapore.

3. Co-Evolution of Supporting Industries in Singapore

The rapid growth of HDD assembly activities in Singapore had induced a correspondingly rapid development of various supporting industries. Table 6 earlier gave an indication of the breadth and depth of supporting industries that have been spawned in Singapore by the HDD industry. These range from printed circuit board (PCB) and flex circuit board (FCB) manufacturing, PCB/FCB assembly and contract manufacturing, disk media sputtering and chemical manufacturing, to precision engineering services (die-casting, metal stamping, tool and die, mould making, precision machining and plating of various mechanical components such as baseplates, cover and actuator arms), clean-room design services, automation equipment, spindle motors, I/O cards, connectors and manufacturing of drive related ICs. By the late 1990s, practically all of the electronic components and precision mechanical parts that go into a HDD assembled in Singapore could be sourced locally or within South East Asia (heads, precision suspensions).

Table 8 shows the estimated pattern of input sourcing for four HDD assemblers in Singapore from the early 1990s to the late 1990s compiled from different information sources. While the definition of what constitutes inputs varies according to the sources, a rough estimate of the proportion of drive input costs which consisted of precision engineering and printed circuit board assembly services is about 40% in the mid-1990s. If we assume that about 30% of these were sourced from Singapore, then the local procurement for these two items could amount to about S$1.6 billion in 1996. This is equivalent to about 30% of the total output of Singapore's precision engineering and contract manufacturing industry in 1996.

More than a hundred supporting industry firms in Singapore are known to have been significant suppliers to the HDD industry. In numbers, by far the largest group is in precision engineering services such as the machining of actuators/e-blocks, metal stamping of baseplates and covers, and associated activities such as surface treatment and die casting. Nearly all these firms are local. Another important group is PCBA, which is primarily local but had some foreign firms as well (e.g. SCI). Three of these local PCBA firms (Venture, Flextronics and Natsteel Electronics) now rank among the top ten electronics contract manufacturers in the world. A fourth major local contract manufacturer, JIT, had recently entered the drive assembly business by doing turnkey assembly for a new, small form-factor drive company Halo.

While many of these were established to serve other electronics industries in Singapore and later moved into supplying the HDD industry, a significant number started with the industry itself. The latter is particularly true in the precision engineering sector. Many of these supporting industry firms today continue to supply not only the HDD industry, but also the various electronics manufacturing and assembly industries in Singapore, including consumer electronics, computers and other peripherals like ink-jet printers and monitors, and telecommunications equipment. Nonetheless, supplying the HDD industry has played a very important part in propelling the growth of the largest local precision engineering and contract manufacturing firms.

The contribution of HDD to the development of the local supporting industries can be gauged not only in terms of the volume of local procurement dollars generated, but also in terms of the extent to which it has induced technological upgrading of these industries. An earlier study shows that the transfer of technology from the electronics assemblers to their supporting

industries, including both direct and indirect transfer, has been substantial (Wong, 1992). More importantly, it shows that there was a larger technology investment inducement effect, whereby the supporting industries demonstrated a higher propensity to invest in technological upgrading when they perceived that a long-term supplier-buyer relationship with their buyers would reduce market risk. Four of the major HDD assemblers were covered in that study. Another indication of the importance of HDD majors to technological upgrading of local supporting industries is the Local Industry Upgrading Program (LIUP) launched by the government in 1986 to facilitate technology transfer from MNCs to local suppliers in general. All the HDD assemblers in operation at that time were selected for participation. A later study (Wong,1997) covering the sources of technology acquisition by 109 manufacturing firms in Singapore included about a dozen precision engineering and contract manufacturing firms that are known to be suppliers to the HDD industry. These firms indicated that "learning from the product specification and feedback from customers" was the single most important source of technological learning for these firms, ahead of recruiting experienced engineers and own R&D. These findings suggest that the HDD majors had stimulated technological upgrading of local suppliers through the indirect exposure effect and investment inducement effect, rather than direct technology transfer/technical assistance.

Essentially the same findings emerged from a more recent survey of 13 major Singaporean suppliers to HDD majors (see Annex A). As can be seen from Annex Table 11, learning from customer's product specification was ranked by the suppliers to be the most important source of technology acquisition, followed by "learning by doing" and "own R&D". "Learning from equipment suppliers and vendors" and "technology transfer/technical assistance" were found to be of more moderate importance. It is interesting to note that, five years ago, the latter two factors were ranked second and third respectively. Thus, there appears to have been an increase in the innovative capacity of the local suppliers over the last five years.

The growing technological capability of the local supporting industries in Singapore is also reflected in the emergence of a number of relatively large local precision engineering firms and contract manufacturers that have become highly competitive internationally. Of the twenty odd precision engineering and contract manufacturing firms that had grown large enough to be listed in the local stock exchange over the last 8 years, about two-thirds are known to have benefited significantly from being suppliers to the HDD industry at key stages of their corporate growth. Table 8 shows the extent of dependence on HDD business among the 13 Singaporean precision engineering and PCBA/contract manufacturing firms that were recently listed on the Singapore Stock Exchange. As can be seen, the dependency ratios ranged from about one-third to 96%. Over time, most of them had reduced their dependence on the HDD industry, although a few had remained highly focused on being specialist suppliers to the HDD industry (e.g. MMI, Brilliant). Some had even completely moved out of serving the HDD industry altogether (e.g. Venture Manufacturing).

Nearly all of the bigger supporting industry firms have also internationalized their operations to neighbouring ASEAN countries as well as to China. Table 9 shows the pattern of internationalization of manufacturing operations of 14 leading local supporting industry firms from Singapore for which data are available. As can be seen, the cumulative number of relocations to overseas production reported by these firms has doubled from 1994 to 1998. On average, there

were 4.3 overseas production sites per firm. By far, the largest number of these overseas production facilities are located in Malaysia (60%), followed by China (18%), Thailand (10%), Indonesia (6.7%) and Philippines (3.3%). However, there has been a significant shift over time; while manufacturing investment into Malaysia accounted for almost 80% of all overseas manufacturing investment prior to 1995, they constituted just 42% in the period after 1994. Within Malaysia, the biggest numbers have gone to Johor, the State of Peninsular Malaysia adjacent to Singapore, followed by Penang. An examination of the key supporting industry players in Penang, Malaysia shows that Singaporean firms are significantly represented (Haggard, Li and Ong,1998).

A couple of examples illustrate how the HDD industry stimulated the growth and technological development of local supporting industry firms. MMI, a precision engineering firm was formed in 1989 by Mr. Teh Bong Lim. A mechanical engineering graduate who had worked for about 8 years in a non-manufacturing-related business, he was convinced that there was an opportunity to ride on the back of strong HDD growth in Singapore by starting a precision engineering firm. He targeted Conner as his first customer because of the active outsourcing strategy of Conner at that time. By adopting the latest process technologies and being able to deliver good quality at low cost, MMI's business grew rapidly from S$4.7 million in the first year (1990) to $34 million in 1993, and $69 million in 1995. The company invested aggressively in new CAD/CAM technologies, rapid prototyping techniques and advanced supply chain management practices while internationalizing its operations to Malaysia to follow Conner and to reduce costs. MMI was soon able to take on increasing sub-assembly responsibilities from Conner and other electronics firms rather than just machining parts.

Around 1994, Conner was experiencing serious contamination problems with its drives, and the design centre in Colorado started exploring the idea of an extruded baseplate that could do away with e-coating, the suspected source of contamination. MMI was the only supplier which was willing to take up the technical challenge of producing extruded baseplates, a process innovation that promised to reduce costs significantly from the traditional machining method. After months of R&D collabouration with the Conner design people, the company achieved a breakthrough, and became for a while the sole supplier of extruded baseplate. Riding on its enhanced capabilities, MMI was able to diversify its customer base to include MKE and Toshiba, in addition to retaining a strong position with Seagate which acquired Conner. The company revenue grew further to S$165 million in 1997, and was successfully listed on the Singapore Stock Exchange that year. Symbolic of his success, Teh was invited to be a board member of EDB in 1998.

Another interesting example is Natsteel Electronics, which had grown to become the sixth largest contract manufacturer in the world. Founded in 1981 and originally named SinTech, the company originally tried to manufacture and sell desktop PCs and peripherals under its own brand name. Finding that to be difficult, the company shifted to contract manufacturing for other OEMs. Conner again provided the company with its first major break to provide PCBA services to the HDD industry. The Conner contract enabled the company to grow rapidly and attracted Natsteel, a government-controlled steel manufacturer, to acquire it. With the injection of finance and professional management, the company was able to leverage its advanced process capabilities developed through learning to meet the stringent demand of the HDD industry. The company expanded into a major contract manufacturer for other HDD majors (Western Digital, IBM) as well

as a well-diversified range of other blue-chip electronics firms operating in Singapore like HP, Compaq and Apple. The company was listed on the Singapore Stock Exchange in 1997 when it registered sales of over S$1.2 billion.

Besides the development of indigenous supplier firms, the HDD assembly activities also resulted in the co-location of many global MNCs that supply various components to the HDD majors. As can be seen from Table 6, Singapore has one of the largest concentrations of production of connectors and I/O cards in the world, including Adaptec, AMP, Berg, Molex and Methode. Although some of these firms were established in Singapore prior to the HDD industry, all have been major suppliers to the HDD industry. The growth of Berg and Adaptec in Singapore, in particular, were stimulated by the presence of the HDD industry. Nidec recently started spindle motor production and design activities in Singapore, after starting motor subassembly in nearby Batam Island earlier. 3M and a number of other US makers of flex-circuits for the HDD industry also established strong presence in Singapore. The chain of multiplier impacts by the HDD industry can be traced further. For example, Makino Asia, a leading Japanese machine tool maker, started fabricating CNC machine tools and vertical machining centers on a significant scale in Singapore to supply to HDD precision parts makers like Brilliant, Polymicro and BJ Electronics. Similarly, Du Pont's production plant in Singapore supplied resins for PCBs that went into HDD plants in Singapore.

4. Explaining Singapore's Dominance in the HDD Industry in the Region

In the above historical account of the dynamics of development of the various HDD-related operations in Singapore, including the dynamics of co-development of the local supporting industries in Singapore, we have implicitly invoked a number of causal arguments to try to explain how major changes or events occurred at each of the key development stages. In this section, we will make a more systematic attempt to explain the locational and regional specialization pattern over time by examining three clusters of explanatory factors: factor costs and supply conditions; agglomeration economies of industry specific skills and supporting infrastructures; and government policies and regulations. In addition, we will examine how the balance of these factors has changed over time due to technological changes and dynamic interaction with the changing HDD industry itself.

4.1 Factor Costs and Supply Conditions

Our historical analysis of how the HDD industry started in Singapore and interviews with industry informants suggest that factor costs and supply conditions played a major role in Singapore being selected by the pioneer Seagate and perhaps some of the second wave follow-the-leader players. In the early 1980s, Singapore, Hong Kong and possibly Taiwan arguably provided the best factor endowments for HDD assembly activities in Asia – availability of managers who are experienced in electronics manufacturing, a moderately good supply of engineers and technicians, and well-trained and disciplined workforce, many of whom had prior exposure to electronics assembly work. Even though wages for these workers were already higher than in other Asian countries, the availability of supply was probably a more important consideration. Moreover, compared to the US and other advanced industrial countries, these three countries still enjoyed a substantial cost advantage in terms of salaries for engineers, technicians and operators. Fluency in

English was probably an important factor that favored Singapore and Hong Kong more than Taiwan, as were communications and transportation infrastructure. However, Taiwan probably scored better in terms of size and sophistication of local supporting industries like precision engineering and PCBA in the early 1980s.

Factor conditions alone thus could not have explained why Singapore was chosen rather than Hong Kong or Taiwan. Moreover, even after Singapore was initially chosen, factor conditions could not adequately explain why they should continue to concentrate there. In fact, Singapore was experiencing increasing labour shortages and rapidly rising wages in the early 1980s, more so than Hong Kong and Taiwan. Singapore had to rely on importing foreign workers, mainly from Malaysia, to increase the supply of operators to the electronics manufacturing companies. Land prices were also escalating through the late 1970s to the early 1980s. It is true that these problems were temporarily alleviated as a result of a severe economic downturn in 1985. In the wake of that sharp recession, the government introduced a series of sweeping policy changes that had the effect of significantly reducing labour and infrastructure costs for manufacturers. It is thus likely that this more favourable environment may have helped induce the second wave of follow-the-leader players to invest in Singapore in the period from 1985-88. Still, labour shortages and rising wage costs became serious again from the late 1980s, making Singapore's factor conditions unfavourable again in the 1990s. Hence, the continuing expansion of assembly operations by the existing majors and the establishment of new operations by IBM and MKE became much more difficult to explain on the basis of relative factor costs and supply. It is thus necessary to turn to other explanatory factors.

4.2 Agglomeration Economies Arising From "Sticky" Skills and Supporting Industries

If the initial choice by Seagate to locate in Singapore over Taiwan or Hong Kong was somewhat by chance, our historical analysis suggests that agglomeration economies contributed to the next wave of follow-the-leader investments by other HDD makers, i.e. the prior presence of existing firms made it more attractive for new firms to co-locate with the existing ones. Two sources of agglomeration economies can be identified: those arising from supply of local skills and local supporting infrastructure. The first arises from the development of a pool of managerial and process engineering skills and knowledge which is somewhat specific to the HDD industry, but by and large *not* firm-specific. The second condition is important because it helps to increase the effect of agglomeration economies. Evidence disconfirming a firm-specific effect is the fact that the major American HDD firms in Singapore appear to have achieved fairly similar level of process capabilities over time (Christensen 1995), and that there has been quite frequent mobility of managerial and technical personnel among the companies. Besides the prominent inter-firm moves of top managers like Tom Mitchell, Joe Chen, Russell Stern and Jim Steger, my contacts with the industry suggest that there has also been very extensive inter-firm movement of engineers, although no systematic statistics are available.

To the extent that management and engineering skills are not entirely specific to HDD assembly alone, the agglomeration economies arising from local skills probably extend to beyond the HDD industry itself and draw upon the presence of experienced managers and engineers in related electronics manufacturing industries as well. What is important, however, is that such skills are somewhat "sticky" and hence not very mobile across countries, i.e. there has to be some cost to

transferring such skills from one country to another, otherwise, a later entrant firm can easily locate in another country and transplant the needed skills from the first country.

A second possible source of agglomeration economies is the creation of a sizable cluster of supporting industry firms that provide inputs to the HDD assembly operations where there is a geographic proximity advantage that is big enough to offset possible disadvantages in factor costs for the supplier industry. If we look at the various inputs to the HDD assembly operation, the two main supplies that became significantly localized from the inception of the industry to the early 1990s were precision engineering services and PCBA/contract manufacturing. Within precision engineering, we can further divide suppliers into two different value chain activities. The "direct materials" chain produces components or sub-assembled parts that are used in the drive itself. The "indirect materials" chain produces the tools and dies and automation engineering services for the design and maintenance of assembly equipment as well as other services like clean room design, factory layout and materials requirement planning systems. The first value chain itself consists of several related processes, including metal stamping, die-casting, machining, and surface treatment (plating, etc.).

Why should there be an advantage in locating these activities close to HDD assembly? Transport cost is certainly one factor, but this may be offset if a more distant location enjoys a lower cost advantage such as cheaper labour and land. A more relevant cost is the transaction cost incurred by a buyer in finding a good supplier, communicating the production specifications and other requirements, negotiating terms, and monitoring and assuring performance. At the beginning when the parties are unknown, the contact needs to be more frequent and the associated transaction costs tend to be high, and hence geographic proximity of the parties concerned will be an advantage. It is also advantageous to the buyers if there is a large pool of alternative suppliers in close geographic proximity, as this would reduce the cost of finding alternative suppliers if the first one does not live up to expectations, or if there is a sudden increase in demand that the first supplier cannot meet. However, once trust has been established in the relationship between a buyer and one or several suppliers, geographic proximity between buyers and sellers may become less important, as the need for frequent interaction is reduced.

While both of these two sources of agglomeration economies contributed to attracting later HDD entrants to co-locate in Singapore once Seagate started the first assembly there, their relative contributions were likely to have changed over time. The first factor (availability of a pool of managers and engineers that later entrants can tap) was probably more important in the initial start-up years. From the mid-1980s when local precision engineering and PCBA capabilities began to emerge, the availability of local supporting industry was likely to have become a relevant consideration as well. However, as we move into the late 1990s, a sufficiently large number of local supporting industry players had established a strong track record of performance (including ISO9000 qualification, prior customer track record), and as such, the transaction costs to find and qualify vendors had become much lower than before, and hence may have reduced the advantage of geographic proximity once again. Thus, many of the better supplier firms had established good enough relationships with the HDD majors that they were able to continue to service them from operations outside Singapore. For example, MMI no longer maintains any production facilities in Singapore, having relocated all production to Malaysia; the company only retains the product engineering office in Singapore to handle the interaction with their HDD customers there. Close

supplier-buyer relationships remain important, but it can now be achieved without having the production facilities of the suppliers proximate to the buyers.

While the clustering of HDD majors certainly facilitated the development of a larger and more varied cluster of precision engineering firms in close proximity, it should be noted that the production capacity of these precision engineering firms were not entirely specific to supplying precision parts to the HDD industry alone. Because the precision and quality requirements of HDD drive components were among the most stringent of all electronics products, firms that had mastered the capability to supply mechanical components to the HDD industry were typically able to supply precision parts to other electronics manufacturing industries as well. Because Singapore has been able to attract a large number of manufacturing firms in a wide range of electronics industries over the years, the size and diversity of Singapore's precision engineering supporting industry is thus much more than can be sustained by HDD requirements alone. The agglomeration economies of Singapore's precision engineering cluster have thus been increased due to the mobility of supply capacity between those serving the HDD and those serving other electronics segments.

Similar observations can be made of the "indirect materials" services such as tools and dies, automation solutions services, clean-room design, etc. Firms offering tools and die or process automation services need to have close interaction with engineers and technicians at the production shop floor to facilitate fast response and feedback. Moreover, because the skills and assets of these firms are generic enough to support a wide range of electronics manufacturing industries, the HDD industry can draw upon the larger pool of such expertise. The presence of a much larger electronics industry in Singapore since the early 1980s also helped to create the scale economies to support a critical mass of competent local consulting firms specializing in advanced manufacturing facility design and development services (clean room design, energy optimization services, etc.). Such local consulting firms (e.g. Supersymmetry, Perdana Consulting) have contributed to the rapid commissioning of new assembly plants in Singapore. However, it is important to note that many of these capabilities built up in Singapore are not all that sticky, and can be readily deployed outside Singapore, as indeed happened. Over time, the same knowledge-base has also been tapped by the Singapore HDD majors to redistribute assembly operations outside Singapore in countries like Malaysia and Thailand. Thus, the contribution of these factors to agglomeration effects on Singapore are weak at best.

Besides precision engineering and facility development services, the early development of printed circuit board assembly (PCBA) capability in Singapore also constituted an important supporting industry to HDD assembly, and hence added to the agglomeration economies of Singapore's supply infrastructure, especially in the earlier years when this capability was less widely diffused in the region. Like precision engineering, PCBA capability (and more generally contract manufacturing capability) is a generic capability that is deployable across a wide range of discrete electronics manufacturing production. However, unlike precision engineering, the value chain activities for PCBA operation can be more easily integrated, and indeed, a number of large, multi-national firms that specialize in PCBA have emerged globally (e.g. SCI, Jobil and Solectron from USA, and Venture and Natsteel Electronics from Singapore). Thus, there is a less compelling reason for geographic clustering of PCBA activities compared to precision engineering. Nonetheless, a preference for proximity can still be observed for firms that chose to perform the

PCBA activity in-house: Seagate had chosen to relocate its PCBA plant to southern Johor, just across the causeway from Singapore.

The other major HDD inputs are disk media and read/write heads. The sub-assembly of read/write heads is one of the most labour intensive operations. Consequently, although this operation was originally started by Seagate in Singapore, it was the first activity to be relocated to a lower labour cost location like Thailand. The growth of Seagate's head assembly operation in Thailand has in turn induced investment by head makers such as Read-Rite into Thailand to be geographically proximate to Seagate (see Brimble and Doner 1998).

Until recently, there was little reason for disk media to be clustered in close proximity to the HDD assemblers. However, some industry analysts have suggested that, with increasing density of data storage capacity being squeezed into the same disk media area, reduced yields arising from disk contamination in the assembly process is becoming an increasing concern, especially for high end disk storage where assembly yields can be quite low (around 60% is not uncommon during ramp-up of new high end drives). There may thus be a technological reason for the disk media manufacturers to be located closer to the drive assemblers, so that yield problems can be more easily diagnosed and isolated. This may be a partial reason for the recent concentration of disk media production in Singapore, and which may in turn reinforce the desirability of high-end HDD assembly to remain in Singapore.

In summary, the creation of local skills and supporting industries by the HDD majors in an earlier stage may have reinforced the attractiveness of Singapore for further expansion of HDD production at later stages, but the effects were unlikely to be very strong, and in any case may have declined over the years as the local skills and supporting industries became less sticky and increasingly replicated outside Singapore. It is thus necessary to examine the additional impact that government policies may have on causing HDD assembly to remain so concentrated in Singapore.

4.3 The Influence of Government and Other Institutional Factors

There is no doubt that the Singapore government had made active and significant efforts to attract and sustain HDD-related investments in Singapore. The issue is what actual impact such promotional policies had. While it is difficult to isolate the effect of public policies from other causes, the comparative analysis of the different trajectories of HDD industry development between Singapore and her ASEAN neighbours strongly suggest that differences in public policies has been a major factor.

In one sense, Singapore's public policy towards the HDD industry can be understood as part of a broader strategy of leveraging MNCs to create high value added jobs and to induce productivity growth through continuous technological upgrading (Wong,1999, Low et.al.,1993). Thus, many of the factors that attracted HDD investments into Singapore, and that sustained their subsequent expansion, were actually not specific to the HDD industry. Nonetheless, there were some policies and programs that were highly industry specific. In what follows, therefore, we will try to identify, where appropriate, the more specific public policy influences from the more general ones, bearing in mind, however, that it may be difficult to isolate the impacts of one from the other. For convenience, we further divide the discussion in terms of the following policy categories: DFI tax

incentives and promotion policies; general policies conducive to DFI; labour market and skills development policies; supporting industry development policies; technological upgrading and R&D promotion policies. In view of the fact that some policy instruments actually have impacts on more than one of these dimensions, we will also discuss the issue of policy coordination and synergistic relationships among policies.

DFI Tax Incentives and Promotion Programs

Generous tax incentives and efficient government bureaucracy to facilitate new business start-up have undoubtedly contributed to Singapore's ability to attract Direct Foreign Investments (DFI). Most of the investment in drive assembly investments appear to have received pioneer status, which granted a tax holiday for a specified time period, usually 5 years. Similarly, the continuous upgrading and expansion of the existing assembly operations of HDD majors in Singapore had benefited from significant tax incentives such as an accelerated capital depreciation allowance. In addition to these tax incentives, our earlier description of the various cases of HDD investment indicate that the government also actively assisted the HDD majors in achieving quick start up. For example, the recent move by IBM to transfer its assembly operation in San Jose to Singapore received not only generous tax incentives, but also significant expediting help from various government agencies concerned with making production facilities available on very short notice.

While tax incentives were certainly an important policy tool in attracting HDD investment into Singapore, our interviews with most of the HDD majors, especially Conner and CDC, suggest that other factors were often cited as important as well. Similarly, while the aggressive marketing efforts of EDB and the professionalism of the officers involved in the promotional efforts may also have been important in winning over some of the HDD investments versus other competitive locations; such selling efforts could not have succeeded unless Singapore had genuine advantages to offer to foreign investors. In other words, we can not examine the impact of tax incentives and promotional efforts in isolation from other, often broader, policy influences that make Singapore such a conducive place for DFI. Indeed, many of the tax incentives offered by Singapore have been imitated by neighbouring countries like Malaysia, especially since the late 1980s; in spite of this, Singapore has continued to attract more HDD investment than Malaysia over the last 10 years.

Broader Policy Influences that make Singapore conducive for DFI

Much has been written about the combination of factors that together make Singapore conducive to DFI (see e.g. the annual World Competitiveness Report, and Low et.al.(1993)). Besides the openness to trade and financial flows, another important factor that has frequently been cited by investors is the heavy pro-active investment in public infrastructure by the Singapore government in the form of excellent transportation and communications network facilities, industrial parks, high quality business and financial services, efficient government services and cost competitive public utilities.

While not specialized for the HDD industry, efficient communications and transportation services are of particular importance to a dynamic industry like HDD manufacturing, where high volumes of procured parts and fast time to market requirements put a premium on the infrastructure

that facilitates effective logistics and supply chain management. It is certain that the presence of world-class transportation and communications infrastructure in Singapore has contributed to making Singapore a preferred choice for locating final drive assembly despite her high wage cost. Given the imperative of reliable global supply sourcing and quick time to market, efficient and low-cost manufacturing operations can be undone by bottlenecks not just in the physical infrastructure (e.g. port handling capacity and frequency of connecting ships/flights), but also in the soft infrastructure like customs clearing procedure. JTS, a US HDD maker, had found this to its woe when it started drive assembly operations in India (Interview with JTS). The ability of Singapore to supply functioning industrial facilities for quick start-up by HDD majors had also been repeatedly mentioned as a facilitating factor in our earlier accounts.

Another general DFI facilitating factor that has been frequently cited pertains to public policies to enhance the supply of skills and the public institutions that foster harmonious industrial relations (see e.g. Soon(1993)). There is no doubt that the early adoption of a liberal immigration policy to attract foreign skills and talent has contributed significantly to overcoming the shortage of indigenous skills supply. The development of legislation restricting the development of militant trade unions and the tripartite consultation system involving labour, government and industry had similarly been credited with maintaining a harmonious, non-confrontational labour relations environment that is attractive to DFI. In addition, the early public policy decision to adopt the use of English as the medium of education throughout the entire educational system has made the Singapore workforce much more attractive to DFI.

Last, but not least, we probably need to add even broader factors like political and macro-economic stability, a clean and efficient government, clear rules of law safeguarding property rights and business contracts, and a cosmopolitan living environment that expatriate managers find pleasant.

Supporting Industry Development Policy

Beyond the above general factors, however, the Singapore government has also contributed specifically to the development of the precision engineering industry cluster. One early contribution was the public investment in a large number of training institutions for precision engineering skills, which provided the critical human resources for the subsequent development of the precision engineering industry (Soon 1993). As the skill levels demanded by the industry increased over time, the training programs also got upgraded steadily, with increasing emphasis on training at the polytechnics – at both university undergraduate and postgraduate levels. At the same time, more specialized training programs were evolved to cater to the specific skills upgrading requirements of particular industries.

A particularly interesting public program that had made a positive impact on local supporting industry development was the Local Industry Upgrading Program (LIUP), which was established in 1986 to facilitate the upgrading of local industries that supply MNC manufacturers (Wong(1991) and Soon(1994)). Many of the local firms that received assistance through the LIUP program were in the precision engineering cluster. As mentioned earlier, all the HDD majors participated in the LIUP program.

An innovative feature of the LIUP program is the manner in which it seeks to leverage the competencies of the MNCs rather than to develop a separate public agency to provide industrial extension services as is typical of many developing countries. Through LIUP, the EDB undertook to pay for the salaries of an experienced engineer who is an employee of a participating MNC. Carrying the title of LIUP manager, the primary function of this engineer is to identify local suppliers with potential to upgrade into globally competitive suppliers, and to use the resources available within the MNC to provide them with focused assistance. The assistance program usually starts with the LIUP manager performing a diagnosis of the operational problems and management weaknesses within the local supplier firms, drawing upon his experience at the MNC and his knowledge of the benchmark standards of the MNC. Depending on the diagnosis, the LIUP manager then recommends the local supplier firms to undertake various upgrading measures. Where possible, the LIUP manager would draw upon the resources of the MNC, e.g. inviting the suppliers to send workers to attend quality training programs that the MNC conducts for her own employees, or getting the MNC to design vendor development programs that best address the problems of the suppliers. At the same time, being well-versed with the various public assistance programs available from the government, this LIUP manager is well-placed to advise on the types of public assistance to apply for, and to facilitate the application process. Finally, the LIUP managers from the different MNCs are required to meet regularly at EDB to pool their knowledge concerning the key problems faced by the suppliers under their care, and to share MNC practices in assisting suppliers. Through such knowledge sharing sessions, the LIUP managers were able to leverage resources and know-how beyond their own MNCs; at the same time, EDB senior officers were able to get a comprehensive picture of emerging industry problems and concerns, which may lead to fine-tuning of existing assistance programs or the development of new ones.

It is important to note that LIUP was implemented with the strategic intent of facilitating technological upgrading of the local suppliers, and not to protect them from global competition through local content requirements. MNCs participating in the LIUP program are *not* required to procure from the local suppliers that they take on as partners under the program, although many of these partner firms are their vendors in practice. Moreover, while the early emphasis is on leveraging the MNCs to help the local suppliers to improve their processes and general management practices, the goal is to move towards a second stage where the local suppliers and their MNC buyers would be able to undertake joint product/process development. Another aim is to encourage non-competing suppliers of the same MNC to cooperate in joint product/process development.

While there is no comprehensive study of the impact of the LIUP program in recent years, an earlier study (Wong, 1991) covering a sample of electronics supporting industries found a high degree of satisfaction with the assistance that they received through the LIUP program. A later study of a larger sample of LIUP recipient firms (Kok(1993)) similarly showed positive evaluations of the program by the recipient firms. Five out of the 13 supporting industry firms interviewed by the author in 1997 were participants in the LIUP program (see Annex A, Table 17). All indicated satisfaction with the program.

While no comprehensive statistics are available, it is interesting to note that quite a few of the LIUP managers are known to have subsequently left to join one of the supplier firms that he was helping. This phenomenon suggests that the LIUP program can be interpreted as an effective device for developing competent managers for local firms: the LIUP manager not only brings with him

knowledge and experience gained at a world-class MNC, but also familiarity with the working environment and culture of local SMEs.

While the early policy efforts to promote supporting industry development concentrated on general technological upgrading, these had been complemented by more recent policy efforts to promote technological innovation and R&D, which will be discussed in more detail later. There was also a public effort to encourage industry upgrading through industry self-help. An industry association, the Singapore Precision Engineering and Technology Association (SPETA), was set up in the late 1980s with active encouragement by the government to help their members to upgrade through industry-sponsored training courses, information dissemination, etc. Last, but not least, many of the precision engineering firms that have grown successfully have benefited from the various financial assistance programs for SMEs. For example, the Small Industry Technical Assistance Scheme (SITAS) (later renamed as the Local Enterprise Technical Assistance Scheme (LETAS)) and the Local Enterprise Finance Scheme (LEFS) provided public subsidies to SMEs to invest in technological upgrading and productivity improvement. More recently, since 1996, a new Innovative Development Scheme (IDS) has provided public subsidies to firms to invest in product or process innovations that promise to improve competitiveness substantially. As can be seen from Annex Table 17, 69% of the 13 local suppliers received assistance through SITAS, and 23% benefited from IDS. In addition, the surveyed local suppliers also benefited from various other tax incentive schemes, ranging from 23% for R&D grants to 62% for acquisition of capital equipment.

Labour Market and Skills Development Policies

As mentioned earlier, public educational policies and government policies to promote industrial skills upgrading in general had been identified as having significant impacts on the quality of the Singapore workforce (Soon, 1993). While not targeting at the HDD industry specifically, the various public programs in skills development have undoubtedly contributed to the development of the reservoir of HDD manufacturing process engineering skills by augmenting the supply of well-trained technicians and engineers. A liberal immigration policy and active government programs to attract foreign talent have also helped. The early establishment of the Skills Development Fund(SDF), a compulsory "tax" on payroll that a company can only utilize by sending its employees to approved training programs, has also been credited with raising the intensity of training by manufacturing firms in Singapore in general (Soon, 1993). Our interviews with the HDD majors and their suppliers suggest that all of them have utilized the SDF extensively for worker training.

Besides training through SDF, a number of additional subsidized skills upgrading programs have been utilized by HDD majors and some of their suppliers. For example, through the Industrial Automation promotion program, various incentives were given to manufacturers to invest in automation and to adopt computer-integrated manufacturing technologies in the late 1980s and the first half of 1990s. A study of automation adoption among three HDD majors in the mid-1990s (Wong et.al., 1997) found all of them utilizing the incentives to invest in process automation. Another incentive scheme, the Initiative in New Technology Adoption (InTech), was also used by one of the HDD majors to send engineers to the US to be trained in advanced automation technologies.

Besides giving subsidies to the individual firms to upgrade their manufacturing process, the government also established an Institute of Manufacturing Technology (GIMT) to develop new manufacturing technologies and diffuse them to local industries. The institute also actively sought to conduct joint R&D with manufacturing firms. A number of the HDD majors and their suppliers had been involved in R&D collabouration with GIMT.

Besides these non-industry specific manpower development policies and programs, a recent specialized training program was developed for the HDD industry, in the form of a training program in storage technology conducted by a polytechnic (the Singapore Polytechnics) in collabouration with the International Disk Drive Equipment and Materials Association (IDEMA). While this program is too new to have any visible impact, it is illustrative of the continuing public policy effort to innovate new manpower development programs to meet changing industry needs.

R&D Promotion Policy

In addition to the policies to encourage HDD majors to improve their process technologies, the government has also been actively encouraging them to start drive design and product R&D activities in Singapore. This is being done in two ways. First, through the National Science and Technology Board (NSTB), the government provided a number of R&D incentive schemes such as the Research & Development Assistance Scheme (RDAS) and the Research Incentive Scheme for Companies (RISC) which effectively subsidized private firms' investment in R&D. These schemes are open to both local and foreign firms, and are not confined to the HDD industry. All the HDD majors in Singapore are known to have been recipients of some forms of R&D grants from NSTB, although the actual amount of the grants received has not been disclosed.

The second way represents a more targeted approach with respect to the HDD industry. In 1992, NSTB established the Magnetic Technology Center (MTC) specifically to build local capabilities in selected core magnetic storage technologies. MTC was encouraged to work with HDD companies to establish R&D collabouration, both as a technical support service to the HDD majors' operations in Singapore as well as to leverage the latter to hasten local capabilities development. In line with the strategic diversification into optical storage industry, MTC subsequently evolved into the Data Storage Institute (DSI), with a broader mandate to develop local innovation capabilities in both magnetic and optical storage technologies.

While it is probably still too early to assess the impact of DSI on product innovation capabilities of the Singapore-based data storage companies, the fact that DSI has been able to attract several leading HDD companies in the world to participate in R&D collabouration projects suggest that it has already developed a certain level of core competencies that are being sought after. While still small, the growing portfolio of patents filed by DSI is another potentially positive indicator. And although only one company has been spun off so far, more are expected in the near future. According to an international expert from IBM who sits on the board of advisors of DSI, the institute can be counted as among the top six data storage R&D institutions in the world today, the only one outside USA and Japan. A leading MIT professor in chemical engineering has also given a very high assessment of some of the researchers working in DSI.

Interaction of Public Policies and Agglomeration Economies

Although I have discussed the various public policies separately, it is important to recognize that the full impact of these policies often comes through their synergistic interaction. For example, the LIUP program served as a focused means for diagnosing areas of weakness of local supporting industries, but for these identified weaknesses to be rectified, there must be complementary resources that can be drawn upon such as LETAS, SITAS, etc. As emphasized earlier, it is interesting to note that LIUP was implemented within a policy context of encouraging technological upgrading (where the local suppliers are helped to raise their capabilities) rather than legislating local contents (where local suppliers are protected from global competition and hence have less incentives to upgrade). The outcome of the LIUP program may have been different if it had been implemented within the latter context.

Moreover, some of the public policies also interact strongly with the dynamics of development of agglomeration economies. For example, the early emphasis on attracting DFI, when most of the countries in the region were still not that favourably disposed to DFI, had surely given Singapore crucial first mover advantages that enabled her to accumulate agglomeration economies (Wong 1995). Once a critical mass of such industries had developed, Singapore would be able to maintain a locational advantage even if other countries start to adopt the same DFI incentives as Singapore.

It is important to recognize that many of the government policies targeted at promoting the HDD industry and its local supply infrastructure have also been informed by an explicit industry cluster development strategy since the early 1990s (MTI, 1991, Porter,1990). As evident from the *Strategic Economic Plan* formulated in 1991, the government explicitly recognizes the need to promote industrial development as an integrated cluster linking downstream end-product industries, upstream supporting industries, and enabling capabilities. In line with this strategy, there was strong emphasis on inter-government agency cooperation and coordination in formulating industrial policies and implementing industrial promotion programs. There was also strong emphasis on involving all the various players involved in particular industry clusters in policy formulation dialogue and implementation consultation. Industry players are also strongly represented in the board of government agencies involved in industry and technology promotion, industrial training and tertiary educational institutions. In particular, senior managers of the HDD majors have regularly been appointed to board membership in EDB and NSTB.

Application of this cluster industry promotion approach to the HDD industry is going beyond building the precision engineering and PCBA supporting industries. Since the mid-1990s, the Economic Development Board (EDB) has focused on attracting disk media-related companies to locate their production in Singapore as well, as documented earlier. Finally, besides promoting investment in disk media and upstream product innovation capabilities, the government is also actively promoting a strategic diversification into the optical storage industry and other related industries such as semiconductor design. The strategic intent is to leverage the existing HDD industry capabilities and infrastructure to grow new data storage industries that in turn strengthen the development of an underlying core of technological capabilities related to data storage. By leveraging the existing capabilities, this data storage cluster strategy seeks to

generate agglomeration economies around core technologies, manpower and supporting infrastructure.

Assessing Policy Impact

In the absence of detailed, carefully controlled policy impact studies, it is not possible to quantify the precise impact of public policy on the HDD industry development in Singapore. Nevertheless, taken together, the above outline of major policy influences suggest that the overall impact of government policy has been positive. This is consistent with the views expressed by senior managers of HDD majors that we have interviewed, press reports of public statements made by senior HDD managers, as well as various known studies cited earlier.

Another indication of the overall favourable evaluation of public policy comes from a comparative analysis I have conducted of a sample survey of HDD suppliers in Singapore versus those in Penang, Malaysia as reported by Haggard, Lim and Ong(1998). Annex A provides a summary of the key comparative findings from these two surveys. As can be seen, one clear difference that stands out from the comparative analysis is the relatively higher proportion of supplier firms in Singapore which gave positive evaluations of the role of public policy versus those in Penang (Annex Table 16-19).

4.4 The Role of Singapore in the Global Competitiveness of US HDD Majors

While the Singapore economy certainly appears to have benefited from the investment of US HDD majors, It is interesting to examine how such investments have helped contribute to the global competitiveness of US HDD companies. While McKendrick (1997) has addressed this question from the perspective of internationalization in general, it may be useful to examine the specific role of using Singapore as a regional production hub. We can do this is by taking a closer look at how the exploitation of the pool of local skills and supporting infrastructure created in Singapore may have contributed to the global competitive performance of the US HDD majors concerned versus others that chose not to locate in Singapore.

As highlighted in McKendrick(1997), HDD firms have historically had to pursue both rapid product innovation and continuous cost cutting to survive competition. This competitive requirement translates directly into pressure to develop and maintain flexible production capabilities. How important, then, are the localized skills and supply infrastructure to enhancing the flexible production capabilities of US HDD firms in Singapore?

To address this question, we need to examine the requirements of flexible production in greater detail. As widely discussed in the industrial engineering literature, the concept of manufacturing flexibility is quite complex (see e.g. review by Sethi and Sethi 1990). Field interviews at several HDD assembly plants in Singapore suggest three key components of production flexibility:

(a) Rapid production ramp-up capability for major new products

Because of increasingly short product life-cycles, each new generation of drives that incorporates the latest product technology innovations must reach the market fast to maximize the first mover's window. Hence, HDD assemblers must be able to ramp up production of new drives quickly (Terwiesch,C., R.E.Bohn and K.S.Chea,1999). This production volume capability in turn requires rapid tooling, fast response in the supply of components, especially those that represent new designs not shared with older product lines, fast process engineering development and commissioning of new production lines, and a responsive logistics management system to cope with the spike in volume. Rapid ramp-up also extends to rapid development and commissioning of new manufacturing facilities.

(b) Product mix flexibility

In between major new product innovations, the HDD assemblers face rapid changes in the mix of market demand for specific products; the "sweet spots" i.e. the most popular storage/form-factor configuration, can shift several times a year. The HDD assemblers must therefore be able to maintain sufficient product mix flexibility, which in turn leads to requirements for fast set-up time and operations management flexibility. HDD assemblers must also be able to ramp down fast to avoid being stuck with obsolete models.

(c) Continuous process improvement capability

Last, but not least, HDD assemblers need to have the capability to continuously improve the manufacturing process to achieve higher yield/quality and to drive down costs. This calls for "continuation engineering" skills such as progressive automation of assembly process steps, speeding up of drive testing, design of more flexible work stations that can handle a wider range of product configurations, etc. The challenge is to have the flexibility to implement regular engineering changes and frequent fine-tuning of the operations management procedures, while ensuring that the throughput of the system is not adversely affected in the process.

In order to achieve a high level in each of the above three dimensions of flexible production capabilities, HDD assemblers need to be able to draw upon a significant pool of industry-specific process engineering skills, both within the assembly plant as well as in the related supporting industries.

How Process Management and Engineering Capabilities Contribute to Flexible Production

Recent studies on the implementation of automation among electronics firms in Singapore suggest that achieving greater flexibility has been a major motivation, in addition to lowering operational costs (Wong and Ngin 1997). Another study covering specific case studies of four Singapore-based HDD assemblers (Seagate, Conner, Western Digital, Micropolis) confirmed the importance of flexibility as a major objective of automation investment (Ang et.al. 1997). These case studies also found that the HDD assembly plants automated a substantial part of their assembly operations through their own, locally developed in-house process engineering capabilities. Indeed, although new product development remain located in their parent headquarters in the USA, all the manufacturing plants have introduced some form of concurrent engineering, with their process

engineers closely involved quite early in the product design phase by extended posting to US headquarters. As several of the senior engineers interviewed suggested, the highest process engineering capability of HDD makers now resides in the engineers in Singapore plants, not in the US. In one plant, there was a clash between Singapore engineers and engineers in US headquarters over how to design and implement a new automated process in the Singapore plant. The Singapore team eventually prevailed when their approach was demonstrated to be superior (private communication).

The high level of process engineering capabilities developed among HDD plants in Singapore can also be seen from the fact that, when these HDD companies opened other assembly operations elsewhere in the world, they have often resorted to the use of Singaporean engineers to "transplant" their process design and operations knowledge to these other plants. We have already mentioned the example of Conner using the Singapore operation to manage the transplant of new assembly operations in Penang, Scotland and China. Less dramatic but just as important, most of the HDD majors have used their Singapore operations to serve as "transfer stations" for ramping up new drives and transferring them to other assembly locations: they were typically tasked with developing the process to make the latest product lines, and after these become stabilized and matured, they were subsequently tasked with transferring them to other lower cost locations. Thus, despite significantly higher wage and land cost, Singapore was able to maintain a competitive positioning as the hub for "lead" manufacturing plants. Although some HDD majors (e.g. Seagate) had moved away from this “transfer station” model towards direct drive transfer in recent years, some have continued this practice (Western Digital).

How Local Supporting Industries Contribute to Flexible Production Capabilities of HDD Majors

The availability of a sizable, technically sophisticated precision engineering support industry has been commonly cited by senior managers in the HDD industry as a key factor in favour of HDD assembly in Singapore. For example, Singapore is credited with having developed a "diffused" supporting infrastructure that "...can quickly transform design into hardware without deep, high volume commitments, and at the same time provide the flexibility to accommodate the required growth when high volume became a reality...here, you don't have to be one of the "Fortune 1000" to get a vendor attention..." (DiBene1992). Our earlier case studies of the decisions by Conner, CDC and other HDD majors to choose Singapore as their first production location in Asia all pointed to the availability of local suppliers as a major factor. Similar assessments were reported by various senior managers of HDD assemblers when they were interviewed by the local press on the occasion of their announcements of new investment or facility expansion in Singapore. For example, a recent published interview with Seagate management in Singapore cited close relationships with suppliers, flexibility to change lines quickly to respond to customer’s requirements rapidly, and constant and continuous improvement in manufacturing processes as its “productivity secrets”(Electronic Business Asia 1997). Another study covering three HDD firms in Singapore all cited close relationships with suppliers as their key competence (Phun 1997). My survey of 13 supplier firms in 1997 found that over 40% of them regarded their relationships with their HDD customers to be of a long-term, mutual gain nature. The average length of relationships with their HDD customers as reported by these 13 suppliers was 10.8 years.

Reflecting the importance of production flexibility by the HDD majors, the local supporting industry also indicated flexibility as an important competitive factor in securing orders from the HDD majors. As can be seen from Annex Table 8, the survey of 13 local suppliers indicates that flexibility/responsiveness to customers was regarded as the third most important competitive factor by the local suppliers in Singapore, after quality and cost. In contrast, this was ranked fifth among the suppliers in Penang. The survey also found the supporting industries in Singapore to exhibit a higher extent of involvement with their HDD customers than was found in Penang (Annex Table 9): on a scale of 1-5, the supplier firms surveyed in Singapore indicated an average score of 4.4 for new product ramp-up and planning, 4.2 for product modification and improvement, and 4.1 for assembly process changes. The corresponding scores for the Penang sample were in the range of 3.4 to 3.5.

Field interviews by the author with senior management in a number of HDD manufacturers in Singapore, as reported earlier, confirmed the importance that these companies attached to the contribution of local supporting industries to their ability to ramp up production fast, and to adjust production mix quickly. Indeed, when these HDD makers redistributed some of their more mature product lines to neighbouring countries, they have often replicated their buyer-supplier relationship with the same Singaporean precision engineering firms, by inviting them to start-up operations in these countries as well. For example, when Conner started drive assembly in Penang, Singaporean firms were involved in the clean-room design, automation equipment development, and factory commissioning, while several Singaporean precision engineering and PCBA firms were asked to start operation in Penang to supply Conner. The close involvement of Singapore-based suppliers in the relocation activities of HDD majors appears to have continued in later years; as can be seen from Annex Table 9, the Singapore suppliers reported an average score of 3.9 out of 5 on the extent of their involvement in the relocation of existing activities to another country by their HDD customers. In contrast, the figure was 2.5 for the Penang suppliers.

Another manifestation of the continuing ability of local suppliers in Singapore to meet the increasingly stringent demand of their HDD customers is their increasing investment in technological upgrading. As can be seen from Annex Table 15, the 13 local suppliers surveyed in Singapore exhibited significant increases in R&D intensity and training intensity over the last 5 years. More than 60% of these firms have also established some collabourative relationships with local universities or public R&D institutes, in contrast to only 13% in the case of Penang (Annex Table 16).

Flexible Production Capability and Competitive Performance of HDD firms in Singapore

While it is difficult to quantify the competitive advantages of locating production in Singapore versus locating in other locations, it is striking to note that all the surviving independent, major HDD makers that have increased their market shares over the last 10 years have had significant production in Singapore. In contrast, the previously captive makers, DEC, HP and IBM, all lost significant market shares in the same period, despite being acknowledged by the technology press as having among the most advanced product technology for HDD. Their inability to match the merchant makers in manufacturing cost and flexibility is a major factor in their loss of competitive advantage. Indeed, HP and DEC have since decided to exit the market entirely.

Coincidentally, the Japanese HDD majors, which have chosen to locate production within Japan until very recently, have also seen their collective share of the global HDD market shrank over the last 10 years. A number of senior managers of US HDD companies in Singapore who were interviewed by the author suggested that, aside from the inability of the Japanese to match the US HDD firms in product technology, the "hard" automation approach of the Japanese to mass production has been a disadvantage against the "agile", fast ramp-up/ramp-down capabilities of US HDD firms.

The increasing importance of flexible production capability to competitive advantage in HDD assembly operations can also be seen in terms of the emerging cost structure of HDD assembly. As can be seen from Table 10, derived from an industry estimate (Lim 1995), direct assembly labour cost represents only 3% of the total cost of production of one HDD assembler in Singapore, with input materials-related costs accounting for almost 90%. Consequently, the flexibility and cost competitiveness of the input supply infrastructure has a much bigger impact on the overall competitiveness of the HDD assemblers than direct labour cost. Indeed, because yield levels for new high-end drives tend to be low, even a slight improvement in yield through process engineering improvements may contribute more to cost reduction than a significant reduction of direct labour cost (Hampton, 1996, Gourevitch et.al.,1997). Similarly, the razor-thin margins on component parts like baseplates and actuator arms can be wiped out by excess inventory holding and transport costs, hence the importance of close geographic proximity.

To the extent that these two sources of flexible production capability are still not yet widely available in other competing countries for HDD assembly like Malaysia, Thailand and China, Singapore is likely to continue to play an important role in supporting high-end drive production, despite having substantially higher land and labour costs (Table 11). A recent study by Terwiesch,C., R.E.Bohn and K.S.Chea(1999) strongly suggests that the ability to ramp up fast can more than compensate for higher land and labour costs.

With the key Japanese HDD majors strategically committed to growing a separate production hub in the Philippines (Tecson,1999), it will be interesting to see if the US Majors' strategy of continuing their reliance on Singapore as their lead manufacturing hub will prove to be a superior locational strategy.

Last, but not least, with the emerging R&D capabilities of Singapore in HDD technologies as well as related capabilities such as chip design, control algorithms, tribology and optical storage technologies, it remains to be seen whether and how the US HDD majors will choose to exploit these new sources of innovation capabilities to complement what they are doing in the US. To the extent that some Japanese HDD firms are beginning to tap into Singapore's emerging R&D capabilities (some of the DSI R&D collabourators are Japanese), a US firm strategy to use Singapore only for manufacturing purposes may prove to be shortsighted. The recent success of Seagate in designing drives in Singapore suggests the potential for more product innovation activities to be transferred to Singapore.

5. Concluding Observations

5.1 Implications for Theory Development

Our analysis of the emergence and continuing dominance of Singapore in the global production of HDD holds interesting implications for the development of theoretical frameworks explaining how and why industries tend to cluster in physical space.

First of all, our analysis of the HDD industry points to the need to disaggregate arguments about the causes of geographic concentration to the level of specific value chain stages, rather than at the level of the overall industry. Our analysis strongly suggests that the likely importance of various factors such as agglomeration economies, government policies and factor conditions may vary significantly according to the characteristics of different stages in the value chain of an industry due to the different characteristics of the production technology and factor inputs involved. Thus, while the location of read/write heads have been strongly driven by the factor condition of cheap labour supply, with little evidence of agglomeration economies, the location of final drive assembly may have stronger agglomeration economies. Hence, the generalizability of the importance of localized supply infrastructure must be predicated on the nature of the value adding activities involved. What constitutes "local" supply is also likely to change over time, as transportation and communications technologies improve and regulatory barriers decline between regions and countries.

5.2 Implications for Public Policy

Public policy to influence the geographic location of industries is likely to have a stronger effect if there are strong agglomeration economies involved. Concomitantly, the beneficial effects of such policies are likely to be larger if the industries concerned have strong backward or forward multiplier effects that are likely to be sticky. The combination of these two tend to lead to a virtuous cycle of path-dependent growth, whereby an initial investment by some firms help attract other firms to co-locate, which in turn helps to increase the scale of development of relatively localized supporting industries upstream and supporting services downstream. These in turn further contribute to the agglomeration economies of the location. Because of the strong path dependency effect involved and the first mover advantage being conferred, public policy is likely to have a strong influence by helping to enhance the chance of a location being selected for the first investment, by strengthening the agglomeration economies effects, or by deepening the multiplier effects and their stickiness.

Our analysis of the growth of HDD assembly in Singapore suggests that industries that involve the production of complex assembly products which are subject to rapid technological change, short product life cycles and intense competition are likely candidates for public policy intervention. Singapore was able to exploit the demand for flexible yet low-cost production capabilities by US HDD assemblers through a combination of policies that reinforce the forces of agglomeration economies and local multiplier effects. It may have been partly due to luck that Seagate initially chose Singapore for its first offshore production site, but the subsequent concentration of HDD assembly activities in Singapore was the result of a dynamic interaction between increasing demand for flexible production capabilities on the one hand, and the growing

agglomeration of a local skills and supply infrastructure reinforced by government policies on the other. Deliberate government policies to promote DFI by HDD assemblers, coupled with conscious programs to promote the development of local supply infrastructure, have combined to reinforce the agglomeration advantage that Singapore has in HDD assembly despite rising costs and increasing competition for DFI by neighbouring countries. If low-cost competition has been the sole factor, it is unlikely that Singapore could have maintained the high degree of concentration of HDD assembly activities that it has achieved up to now.

To the extent that our analysis of public policy intervention in the HDD industry is generalizable to other industries with similar technological and market competition characteristics, there are significant policy implications for developing countries in general. Firstly, it suggests that a policy of simple market liberalization (like what has been practiced in Hong Kong) or a policy of attracting DFI with tax incentives alone (like Thailand) may not be sufficient to maximize the beneficial returns of such investment to the country concerned. Government policy should extend to promoting the development of local skills and supporting industry infrastructure. Secondly, while the mainstream industrial economics literature tends to emphasize the inability of government to pick winners in emerging industries or technologies, it may be easier for governments in late-industrializing countries to target industrial activities that have already been established in the advanced countries, and which have the desirable characteristics mentioned earlier. The Singapore experience in HDD industry development suggests the usefulness of an integrated industry cluster development and leveraging strategy.

In the HDD industry, we have found that the achievement of flexible yet low-cost production has certainly been a major contributing factor for the continuing dominance of US players versus their Japanese competitors, which until recently have relied on "hard" automation of mass production facilities in Japan. It is also interesting to note that practically all the major American HDD players that had not leveraged East Asian flexible production capabilities had not done well. The recent decision by MKE (the Japanese manufacturing partner of Quantum) and IBM to locate their production in Singapore suggests a belated recognition on their part of the location factor as a source of competitive advantage in this industry.

To the extent that our analysis of the development of the HDD industry in Singapore also lends support to the argument by Borrus(1994) that the development of flexible yet low-cost production capabilities in East Asia by US MNCs have contributed to the competitiveness of these MNCs versus their Japanese competitors, it holds significant policy implications for the home country as well. In essence, the internationalization of manufacturing activities by the American HDD industry, while creating jobs in East Asia, also enabled these firms to retain and indeed grow a significant number of high value-adding jobs in the product innovation stages of the industry value chain.

Thirdly, our findings also suggest a regional complementarity dimension to public policy. We have seen that, as HDD assembly activities continue to upgrade in Singapore, a pattern of complementary regional specialization appears to be emerging in South East Asia, with lower end drives being assembled in countries like Malaysia, China, and the Philippines, more labour-intensive stages of operations located in Thailand, Batam (Indonesia), and the Philippines, and intermediate operations like drive repair and media polishing located in Malaysia. While constantly

competing against one another to move up the technological ladder of manufacturing, the resulting larger, regional clustering of HDD-related activities also provides the whole of South East Asia a regional agglomeration advantage against other regions (e.g. Latin America). In this sense, the spread of HDD-related activities throughout the South East Asian region adds to the advantage of Singapore as a regional hub for high-end HDD manufacturing activities.

Last, but not least, our analysis of the HDD industry in Singapore also indicates that the supply infrastructure for an industry need not be "imprisoned" within that industry, but may in fact represent broad capabilities that can be leveraged to support a wide range of industries, thereby strengthening the host country's overall industrial production capability and flexibility. In other words, the concern that developing countries may become vulnerable by being too dependent on "footloose" global MNCs has *not* been borne out in the case of HDD industry. Singapore's strong position as a regional manufacturing hub has benefited significantly from the presence of the HDD assemblers. A major exodus of such industries has not occurred despite rising wage costs. More importantly, we believe that even if such an exodus were to occur in the future, or that HDD as an industry were to go into decline due to technological substitution by other storage technologies such as recordable CDROMs, DVDs or flash memories, the pool of flexible manufactumg process engineers and the precision engineering supporting industries that have been built up are likely to be able to re-direct their capabilities to other industries. Indeed, the advanced precision and flexibility requirements of complex assembly products like HDD may prepare the foundation for Singapore's entry into other industries.

5.3 Future Prospects for the HDD Industry Cluster in Singapore

As we have argued earlier, the continued dominance of Singapore as a regional hub for HDD assembly right up to the late 1990s reflected not only the comparative advantage of Singapore in terms of skills, supporting industry and the broader superior infrastructure, but also the influence of active government policy to promote such activities in Singapore. However, Singapore may have reached such an advanced stage of development by the end of the 1990s that it may no longer be beneficial for Singapore to continue to have such a big HDD assembly presence. Indeed, as can be seen from Table 1 earlier, while Singapore's production of HDD continued to grow in absolute terms right up to 1998, her share of global production of HDD had started to decline from over 45% in 1995-6 to 39% in 1997 and 36% in 1998.

In the future, the growth of the HDD industry in Singapore had to rely much more on productivity improvement not only against her regional competitors, but also against other manufacturing activities in Singapore. As can be noted from Table 2 earlier, the HDD assembly industry in Singapore has actually lagged behind the overall manufacturing industry in Singapore in terms of labour productivity growth over the period 1987-95. In 1987, the labour productivity of HDD assembly, as measured by value-added per worker, was 10% higher than the average for all manufacturing (S$57,200 versus S$52,300). However, between 1987 and 1991, labour productivity in the HDD industry grew rather slowly, and was no longer higher than the manufacturing industry average by 1991 (S$64,300 versus S$65,500). HDD labour productivity grew faster between 1991 and 1994, but stagnated again in 1995. By then, the average value added per worker in HDD assembly had fallen further below the industry average (S$91,400 versus S$94,200).

It is interesting to note, however, that labour productivity in the HDD industry grew more strongly than the average of all manufacturing after 1995, reaching S$128,400 per worker versus S$105,500 per worker for all manufacturing in 1997. Over the entire 10 year period 1987-97, therefore, labour productivity in the HDD industry grew faster than overall manufacturing. As mentioned earlier, the above statistics on HDD labour productivity, which are measured in current prices, probably significantly understate the true productivity gains in the HDD industry versus manufacturing as a whole. This is because the HDD industry had experienced a much steeper fall in the prices of its output than overall manufacturing output over the last 15 years – HDD prices had been subject to significant price erosion every year. This is reflected in the value added intensity (ratio of value add to total output value), which had been declining steadily from 36.6% in 1987 to 20.8% in 1995, before rising moderately to 22.1% in 1996 and 24.1% in 1997. This rise in value added intensity and labour productivity since 1995 suggests that Singapore may have been able to remain competitive in HDD assembly by focusing increasingly on high-end drives while redistributing lower-end drives to other locations like China.

While the HDD industry had thus been able to outperform the manufacturing sector as a whole in terms of labour productivity growth over the last 10 years, it had lagged behind in terms of average wages. Indeed, average wages per worker in the HDD industry relative to the manufacturing industry average had steadily declined over the years (from $14,600 versus $17,700 in 1989 to $22,000 versus $32,500 in 1997). Moreover, the industry has lagged behind the manufacturing industry as a whole in terms of capital investment per worker – net fixed asset per worker in the HDD assembly industry was less than one-third that of manufacturing as a whole in 1991 (S$16,000 per worker versus S$52,300). Although capital intensity in the HDD industry more than doubled between 1991 and 1997, it was still less than 38% of overall manufacturing in 1997 (S$38,400 versus S$101,000).

In view of the above, the question arises as to why the Singapore government continued to have such a strong focus on attracting and maintaining HDD assembly activities in Singapore through tax incentives. I believe that the perception of significant spillover benefits of HDD assembly to the rest of the Singapore economy has been one major consideration. To be sure, the government had certainly recognized that Singapore should not try to hold on to lower end and mid-range drive assembly, and indeed a significant amount of such drive assembly operations have relocated out of Singapore over the last few years. Indeed, it is such relocation of lower end drives that may help explain the rising level of productivity and value-added intensity after 1995.

I believe the reason for the government to continue to emphasize encouraging high end HDD assembly to remain in Singapore is both economic and political. The economic imperative is that having high end HDD assembly operations would continue to deepen Singapore's general manufacturing capabilities in high precision products, which will continue to have spillover effects on other high precision electronics manufacturing such as key modules of computers and optical storage devices (e.g. precision pickups for CDROM, DVD). The presence of HDD assembly activities are also likely to be perceived as necessary to attract new investments into other upstream manufacturing activities -- disk media sputtering and chemicals manufacturing. More importantly, it is also seen as a foundation for leveraging into the even higher value adding

activities of product innovation – the development of key magnetic storage technologies and hard disk drive design know-how.

As for the political imperative, I believe the Singapore political leadership perceives a need to maintain a strong manufacturing base, even if it is at the expense of more economically using Singapore's scarce land and labour resources because of the consequent recognition of its geopolitical position in Southeast Asia. In a world of completely open markets and liberalized trade regimes, Singapore can arguably concentrate on being a financial, business, logistics and communications services hub to the rest of Southeast Asia, while letting manufacturing activities be redistributed entirely to the regional hinterlands - the way that Hong Kong evolved. However, there are strong possibilities that the regional neighbours will resort to protectionist mechanisms to develop their own services sectors rather than letting Singapore capture these economic activities, at the expense of efficiency loss if necessary. Singapore's commitment to maintaining a strong manufacturing base is thus a strategic insurance against such protectionist tendencies among her regional neighbours.

In light of the above observations, I believe that Singapore will continue to promote the HDD industry cluster over the next 5 years, although the composition of value chain activities being emphasized will change significantly. Building around the high-end HDD assembly activities, the disk media sputtering activities, the optical storage manufacturing activities (CDROM, DVD, etc.) on the one hand, and the R&D capabilities of DSI on the other hand, Singapore will increasingly invest in the related optical storage technologies as well as developing new core competencies in HDD design and R&D. It will be interesting to see if Singapore succeeds in being the first country outside Japan and the US to break into the product innovation end of the global HDD value chain over the next few years.

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Table 1 Singapore's Dominance as a Regional Hub for HDD Industry

Year	Global Shipment (millions units)	Singapore Shipment (million units)	Singapore %
1986	7.8	3.8	48.9
1987	13.6	6.1	45.0
1988	17.7	8.6	48.6
1989	20.8	10.1	48.5
1990	23.8	14.9	62.7
1991	32.6	14.7	45.1
1992	43.9	20.8	47.4
1993	51.9	23.2	44.7
1994	64.7	32.3	49.9
1995	89.6	40.3	45.0
1996	105.0	47.4	45.1
1997	126.0	49.7	39.4
1998	145.0	52.2	36.0

Source: Global shipment data are from disk trend, except for 1998, which is from Trend/Focus;
Singapore figures from Singapore Trade Development Board and refer to domestic export only, i.e. excluding re-export of imported drives

Table 2 Growth of Singapore's Hard Disk Drive Industry (SSIC 38412), 1987-1997

Year	No of Establ't (N)	Output ($ mn)	No Employed (L)	Census Value Added ($mn)	Wages ($ mn)	Fixed Asset (K) $ mn	Total Sales ($ mn)	Export ($ mn)	Input ($ mn)	Other Expend ($ mn)	Estimated Profit ($ mn)
1987	7	3,359.0	21,516	1,231.00	n.a.	n.a.	n.a.	3,256.00	n.a.	n.a.	n.a.
1988	8	3,920.0	21,532	1,326.00	n.a.	n.a.	n.a.	4,890.00	n.a.	n.a.	n.a.
1989	12	5,340.9	25,425	1,417.54	372.08	n.a.	5,419.76	5,312.50	3,894.51	392.92	681.40
1990	13	7,354.7	28,335	1,841.91	425.73	n.a.	7,380.73	7,054.95	5,467.16	449.05	1,012.82
1991	12	7,063.9	27,691	1,780.48	449.25	443.83	7,037.63	6,390.65	5,145.66	694.14	774.93
1992	15	8,266.8	28,695	2,237.81	532.64	468.44	8,284.75	7,692.79	5,882.63	963.59	888.01
1993	11	8,918.7	25,923	2,106.69	463.66	306.79	8,984.70	8,504.43	6,715.41	962.77	776.90
1994	13	11,281.	30,178	2,761.92	573.45	438.90	11,289.33	10,669.9	8,414.72	1,279.99	1,013.52
1995	12	13,899.	31,629	2,891.76	700.76	709.46	13,974.70	12,736.3	10,859.08	1,086.90	1,052.89
1996	12	17,559.	37,305	3,866.60	754.71	818.54	17,319.66	15,016.8	13,478.35	1,342.77	1,983.56
1997	10	19,624.	36,263	4,654.82	797.61	2,315.02	19,456.27	16,889.1	14,743.84	1,129.14	2,953.86

Av Growth % p.a.	Output	Emplymt	Valued Add	Fixed Assets
1987-97	19.3	5.4	14.2	n.a.
1991-97	18.6	4.6	17.4	21.0

Year	Output / Estab't ($ mn)	Labour / Estab't	C. Val. Add / Labour ($)	Wages / Labour ($)	C.Val. Add / Output ($)	Wages / C. Val. Add	Capital / Labour	Export / Sales	Estimated Profit / Sales (%)	Growth Output	Growth C. Val. Add
1987	479.86	1,788	57,213	n.a.	36.6	n.a.	n.a.	n.a.	n.a.	Base Yr	Base Yr
1988	490.00	2,692	61,583	n.a.	33.8	n.a.	n.a.	n.a.	n.a.	16.7	7.7
1989	445.08	2,119	55,754	14,634	26.5	26.2	n.a.	98.0	12.6	36.2	6.9
1990	565.75	2,180	65,005	15,025	25.0	23.1	n.a.	95.6	13.7	37.7	29.9
1991	588.66	2,308	64,298	16,224	25.2	25.2	16,028	90.8	11.0	(4.0)	(3.3)
1992	551.12	1,913	77,986	18,562	27.1	23.8	16,325	92.9	10.7	17.0	25.7
1993	810.79	2,357	81,267	17,886	23.6	22.0	11,835	94.7	8.6	7.9	(5.9)
1994	867.82	2,321	91,521	19,002	24.5	20.8	14,544	94.5	9.0	26.5	31.1
1995	1,158.26	2,636	91,427	22,156	20.8	24.2	22,431	91.1	7.5	23.2	4.7
1996	1,463.28	3,109	104,184	20,231	22.1	19.4	21,942	86.7	11.5	26.3	34.4
1997	1,962.44	3,626	128,363	21,995	23.7	17.1	38,376	86.6	15.2	11.8	19.8

Source: Economic Development Board, Report on the Census for Industrial Production, various years

Note: The Singapore Standard Industrial Classification (SSIC) group 38412 covers the assembly of hard disk drive, floppy disk drive and other and optical storage disk drives. However, as no floppy disk drives have been produced in Singapore since 1987, and the volume of output of optical disk drives remained very small as of 1997, the industry group can be taken as essentially HDD. Note that the industry group does NOT cover disk media manufacturing, which is under a separate SSIC group 38413.

Table 3 Domestic Exports of HDD from Singapore, 1986 – 1998

Year	Units (mn)	Unit Growth (%)	Export ($bn)	Export Growth (%)	$/Unit ('000)
1986	3.8		1.9		0.50
1987	6.1	60.5	3.3	73.7	0.54
1988	8.6	41.0	4.9	48.5	0.57
1989	10.1	17.4	5.5	12.2	0.54
1990	14.9	47.5	7.2	30.9	0.48.
1991	14.7	-1.3	7.0	-2.8	0.48
1992	20.8	41.5	9.0	28.6	0.43
1993	23.2	11.5	9.5	5.6	0.41
1994	32.3	39.2	11.1	16.8	0.34
1995	40.3	24.8	13.5	21.6	0.33
1996	47.4	17.6	16.6	22.6	0.35
1997	49.7	4.9	17.7	7.0	0.36
1998	52.2	5.0	18.4	4.0	0.35
Growth % p.a. 1986-1990		40.7		39.5	
Growth % p.a. 1990-1998		17.0		12.4	
Growth % p.a. 1986-1998		24.4		20.8	

Source : Trade Development Board, Various years

Note: The above figures exclude re-export of HDDs

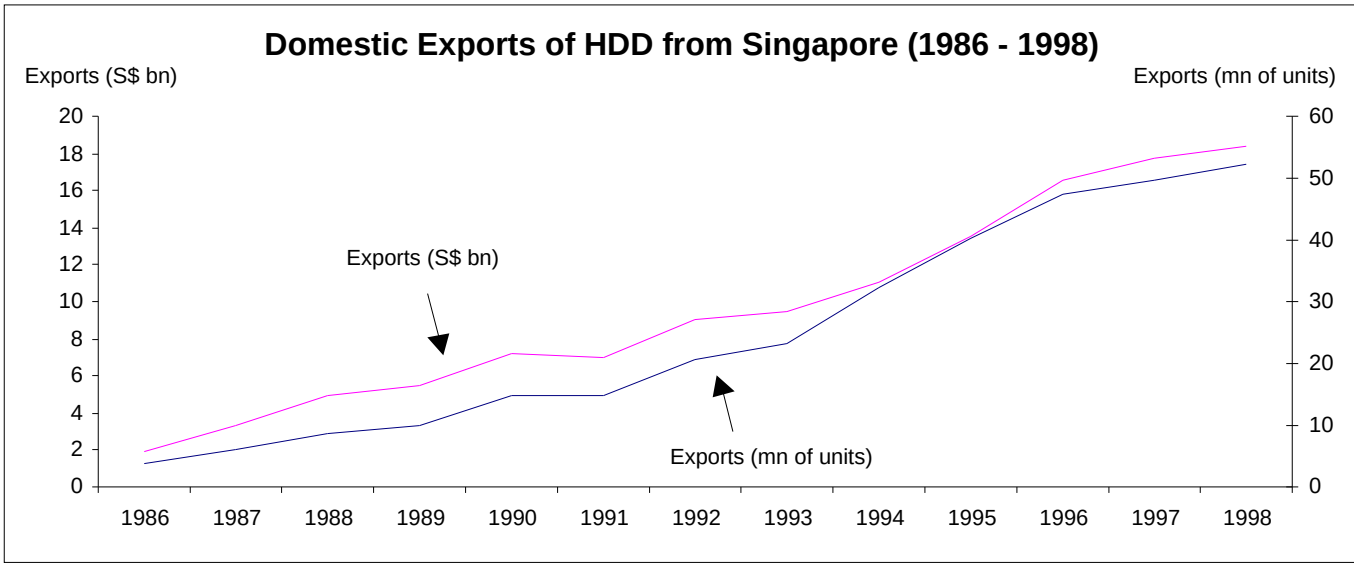

Table 4 Chronology of Hard Disk Drive Assembly Operations in Singapore

HDD Company	Year Founded	Year Established Operations in Singapore	Current Status in Singapore
Tandon HDD	1981	1983	Exited from Singapore in 1987
Seagate Technology	1979	1982	In operation
Computer Memories	1980	1982	Exited
Miniscribe	1980	1983	Acquired by Maxtor
Maxtor Peripherals	1982	1983	Acquired by Hyundai in 1994
Microscience	1952	1984	Exited in 1994
Micropolis	1979	1986	Acquired by ST in 1996; exited in 1997
Rodime	1981	1987	Went bankrupt in 1991
Conner Peripherals	1985	1987	Acquired by Seagate in 1995
Control Data Corp	n.a.	1987	Acquired by Seagate in 1989
Cybernex	n.a.	1987	Exited
Unisys	n.a.	1987	Exited from Singapore in 1989
Western Digital	1970	1988	In operation
Syquest	1982	1989	Exited from Singapore in 1996
PrairieTek Corp	1986	1990	Exited in 1991
Myrica	1991	1991	Exited in 1993
Integral Peripherals	1990	1992	Exited in 1998
Ministor	1991	1992	In operation
MKE	1980	1994	In operation
JTS	1994	1994	Procurement office only; no production in S'pore
IBM	n.a.	1995	In operation

Source: Compiled by author from various press reports

Table 5 Profile of the 8 Largest Global HDD Companies' Operation in Singapore

	Estimated #Units Shipped in 1995 (mn)	1995 Total Worldwide Employment	Employment in Singapore, 1995	Estimated #Units Shipped from Singapore (mn)
Conner	11.7	10,000	3,100	3.8
Maxtor	7.1	7,500	4,500	6.1
Quantum (MKE)	19.6	9,000	2,500	5.0
Seagate	16.7	60,000	15,000	14.2
Western Digital	12.3	7,600	2,100	9.0
IBM	10.5	n.a	1,300	1.0
Micropolis	0.2	n.a.	1,000	0.2
Syquest	0.7	n.a	700	0.7
Sub-total	**78.8**	**94,100**	**29,200**	**40.0**

Source : Compiled from newspaper reports and database compiled by the Globalization of Data Storage Industry Project, UC San Diego

Table 6 Leading Suppliers to the HDD Industry in Singapore

Yr Estab'l	Company	1997 Sales (S$ mn)
Precision Machining, Tools & Die		
1981	Uraco	148.4
1989	MMI	113.0
1987	CAM-Mechatronics	97.3
1981	Seksun	63.7
1989	Heraeus Precision	58.1
1980	Measurex	54.4
1984	Brilliant	46.0
1971	Swiss Precision	25.4
1987	Spindex	19.0
1988	Kinergy	16.0
1984	Wearns Precision	6.2
1979	B.J. Electronics	n.a.
1988	D'MAC	n.a.
1986	Disk Precision	25.0
n.a.	Getech	n.a.
1971	Tata Precision	n.a.
1979	Leksun	n.a.
1979	Polymicro	25.0
n.a.	Sin Yuh	n.a.
1983	TNK	n.a.
n.a.	TPK Precision	n.a.
1988	Westpoint Precision	n.a.
n.a.	Turntech Precision	n.a.
n.a.	Norelco Precision	n.a.
n.a.	Bi-Link Metal Specialities	n.a.
1988	Miyoshi Precision	n.a.
n.a.	Alantec	n.a.
1995	Comport Asia	n.a.
1990	Advanced Materials Tech.	n.a.
Metal Stamping		
1980	Amtek Engineering	258.0
1986	Fine Components	22.3
1986	Oaktech Industries	13.6
1972	Cheung Woh Metal	n.a.
1987	Metal Component Engrg	n.a.
1980	Stamping Tech.	n.a.

Yr Estab'l	Company	1997 Sales (S$ mn)
Electroplating		
1988	ACP Metal Finishing	n.a.
n.a.	Chan Metal Finishing	n.a.
1986	Micro-Team	n.a.
Moulding & Die Casting		
1980	Fu Yu	203.4
1980	First Engrg	68.0
1974	Armstrong	54.4
1980	Hi-P	27.7
1978	Dynacast (UK)	26.5
n.a.	Maxplas	n.a.
1975	Pioneer Die-Casting	n.a.
n.a.	Chosen Holdings	n.a.
n.a.	TPW	n.a.
PCB / FCB		
1988	Gul Tech	127.0
n.a.	M-Flex	n.a.
n.a.	Smart Flex System	n.a.
n.a.	Flexgate	n.a.
n.a.	3M	n.a.
PCBA / FCBA		
1981	Natsteel Electronics	1231.5
n.a.	Venture Manufacturing	708.0
1983	SCI (USA)	516.7
1982	Flextronics	126.4
1987	Tri-M	40.5
1992	PNE Micro Engineering	29.8
1992	Asian Micro	14.0
1985	Speedy-Tech	25.0
Spindle Motors & Components		
1989	Nidec (Japan)	337.4
n.a.	Ferro-Tec (Japan)	n.a.

Yr Estab'l	Company	1997 Sales (S$ mn)
Automation / Test Equipment		
1984	Excel Machine Tools	69.5
n.a.	Dai Huat	n.a.
n.a.	Getech	n.a.
n.a.	Hongguan Technologies	n.a.
n.a.	MHE	23.94**
n.a.	Whyetech	n.a.
n.a.	Laser Research	n.a.
1990	AnA Mechatronics	n.a.
n.a.	Gnegory System	n.a.
Clean Room Design & Engineering		
n.a.	Supersymmetry	19.0**
n.a.	Perdana	n.a.
Media		
n.a.	Mitsubishi Chemicals (Japan)	535.8
n.a.	StorMedia (USA)	210.0**
1995	Hoya Magnetics (Japan)	n.a.
n.a.	Seagate Media (USA)	n.a.
Connectors		
1983	Adaptec (USA)	1228.9
1978	Berg Electronics	200.0
1987	Ultro Technology	81.3
1983	Methode (USA)	34.1
1977	Molex (USA)	158.3
1983	AMP	189.1
ICs, Magnets & Other Electronic Components		
1994	Ugimagnetics (USA)	55.5
1988	ASJ	35.3
n.a.	AMD (USA)	n.a.
1985	Silicon Systems (USA)	n.a.
Heads		
n.a.	Applied Magnetics	n.a.
n.a.	National Micronetics	n.a.

** 1996 Sales Figures

source: Compiled by author from various sources, sales figures mainly from Singapore 1000, EDB directories and company annual reports

Table 7 Changes in Employment in HDD Industry in Singapore, 1990-1995

Company	Employment	
	1990	**1995**
Seagate	13,000	15,000
Maxtor / Miniscribe	5,700	4,500
Conner	5,100	3,100
Western Digital	2,600	2,100
IBM	Not established yet	1,300
MKE	Not established yet	2,500
Micropolis	1,800	1,000
Unisys	800	Exited
Rodime	500	Exited
Microscience	300	Exited
Integral Peripherals	Not established yet	350
Syquest	200	750
Wearnes Peripherals	Not established yet	220
Total	**30,000**	**30,600**

Sources: 1990 - ***Singapore Business*** ; 1995 – EDB Singapore electronics Manufacturing directory 1997/8;

Table 8 Typical Sourcing Structure of HDD Assemblers in Singapore

A) Seagate (1990)

39% of components (surface mount assemblies, precision parts) in Singapore
22% of disk media, ICs from USA
15% of motors, magnetic heads from Japan
24% of others from Thailand, Malaysia and other Asian countries

B) Western Digital (1990)

30% of surface mount assemblies and precision parts in Singapore
34% of disk media, ICs from USA
21% of motors, magnetic heads from Japan
15% of others from Taiwan, India and Europe

C) Maxtor (1994)

PCBA from Taiwan, Hong Kong and Singapore
Heads from USA, Malaysia and Thailand
Disks from USA, Malaysia and Singapore
Motors from Japan and Thailand
Flexlead from USA, Malaysia, Singapore and the Philippines
VCM from Singapore

D) IBM (1997)

PCBA from Singapore
ASICs, heads, media from USA
Baseplates & cover from Malaysia
Magnets, motor from Japan
HGA from China & Mexico

Source : (a) and (b): Straits Times; (c): Lim Yee Juan (1995); (d) Interview with IBM

Note: As incompatible definitions have been used by the different sources, these figures should be taken as indicative only

Table 9 Extent of Dependence on HDD Buyers by Leading Local Supporting Industry Firms

Company Name	Products/Services Provided	%Sales to HDD Customers	Customer since :
Armstrong	Acoustic foams & top cover gaskets	Seagate 1992 25.7% 1994 19.9% Maxtor 1992 5.7% 1994 10.3%	1986 n.a.
ASJ Holdings	Resistors, electronic & non-electronic components	Seagate 1993 40.6% 1994 8.1% 1995 5.7%	n.a.
Brilliant Manufacturing	Die casting, precision components, baseplates	W. D. 1995 97.7% 1996 7.3% 1997 5.4% Maxtor 1996 2.2% 1997 34.0%	1988 1995
Cam Mechantronics	Baseplates, covers, precision machining, die casting & sub-assembly	Conner 1991 93.1% 1993 70.9% 1994 < 60%	1988
First Engineering	Precision injected moulded plastic components & injection moulds	Iomega 1992 9.9% 1994 15.2% Conner 1992 10.4% 1994 9.9% Total dependence on HDD in 1994 = 35%	n.a n.a
Hi-P	Precision machining	All HDD 1994 14.8% 1995 13.1% 1996 10.1% 1997 9.1% 1998 12.3%	n.a.
MMI	Baseplates, covers and VCM sub-assembly	Conner 1994 99.0% Seagate 1996 86.0% (post merger with Conner) MKE 1996 5.0% Toshiba 1996 2.4% Total dependence on HDD in 1996 = 93.4%	1989 1995 1995

Company Name	Products/Services Provided	%Sales to HDD Customers	Customer since :
Natsteel Electronics	PCBA	Conner 1994 41.1% 1995 8.2% Maxtor 1995 6.9% Compaq Jun 1997 8.7% W. D. Jun 1997 8.5%	n.a. n.a. n.a. n.a.
Gul Technologies	Manufacturing of FCB	Seagate 1993 9.2% 1994 25.2% 1995 31.5% 1996 35.3%	n.a.
Ranoda (Subsidiary of Ultro Technologies)	Manufacturing of connectors	Maxtor 1996 10% 1997 85% 1998 78% Seagate 1996 6.5% 1997 9.1% 1998 14.2%	n.a. n.a.
Seksun	Precision machining	Seagate 1991 15.9% 1993 13.7% W. D. 1991 7.1% 1993 1.0% Total dependence on HDD in 1993 = 37%	1986 1988
Spindex	Design & manufacture Precision-machined components & sub-assemblies	Maxtor 1996 2.4% 1997 0.4% 1998 6.4% Total dependence on HDD in 1994 = 14.9% 1995 = 13.0% 1996 = 10.1% 1997 = 9.1% 1998 = 12.3%	1991
Tri-M Technologies	PCBA and contract manufacturing	Conner 1991 89.7% 1993 85.5% 1994 < 70%	n.a
Uraco Engineering	Precision-machining, metal-stamping, die casting & sub-assembly	Seagate 1992 34.2% 1994 39.4% Maxtor 1992 23.5% 1994 11.3% W. D. 1992 5.5% 1994 9.3% Micropolis 1992 11.6% 1994 4.7% Total dependence on HDD in 1994 = 90%	1984 n.a n.a n.a

Source: Compiled from respective companies' Initial Public Offering (IPO) Prospectus & other published sources

Table 10 Location of Overseas Manufacturing Investments by 14 Singaporean Supporting Industry Firms as of end 1998

	1994 or earlier		1995 or earlier		Total	
	No. of Investments	%	No. of Investments	%	No. of Investments	%
Malaysia	23	79.4	13	41.9	36	60
China	3	10.3	8	25.8	11	18.3
Philippines	0	0.0	2	6.5	2	3.3
Thailand	2	6.9	4	12.9	6	10.0
Indonesia	1	3.4	3	9.7	4	6.7
USA	0	0.0	1	3.2	1	1.7
Total	**29**	**100**	**31**	**100**	**60**	**100**

Source :Compiled by author from IPO Prospectus & Annual Reports of 12 listed Singapore firms & newspaper report on two unlisted firms.

Note: While all the 14 companies covered were significant suppliers to the HDD majors, they also had customers in other industries. Consequently, not all their overseas manufacturing investments are necessarily to supply the HDD industry.

Table 11 Estimated Cost Structure of a HDD Assembler in Singapore, 1994

Cost Composition of Assembling a Drive	%
PCBA	36
Heads	21
Disk	14
Motor	5
Flexlead	3
VCM	2
Others	8
Materials Related Subtotal	89
Freight	1
Direct Labour	3
Indirect Labour	3
Facilities Related	1
Depreciation	2
Other Overheads	1
Total	100

Source : Y.J. Lim (1995)

Table 12 Regional Cost Data Comparision,1993, US$

Data Comparison	Singapore	Malaysia (Penang)	Indonesia (Batam)	China Shenzhen	Thailand
Exchange Rate	1.527	2.59	2165	8.68	25.05
Base Labour Rate Per Month					
Operator	382	232	138	55	105
Engineer	1048	619	360	182	327
Manager	1637	967	490	302	458
Provident Fund/ Workmen Compensation	20-22	13-14	2-6	39	0-4.5
Rental psf	1.05	0.46	0.79	0.9	0.13
Foreign Exchange Control	Liberal	Liberal	Liberal	Restrictive	Liberal
Corporate Tax% Year End 1994	27	37	15-35	15-33	37
Pioneer Status Tax Incentives	100%	70%	Nil	100%	Nil

Source : Y.J.Lim (1995)

Annex Table 1 Estimated Sales of HDD companies in Singapore 1990-1996

HDD companies in Singapore	Revenue (S$mn)						
	1990	**1991**	**1992**	**1993**	**1994**	**1995**	**1996**
Western Digital		762.60	1,030.20	1,667.70	1,918.60	2,187.20	2,701.40
Maxtor	639.65	731.79	1,504.79	1,787.98	1,249.74	1,879.95	1,224.07
Conner	1,143.91	1,934.97	1,511.90	1,229.64	1,284.60	1,006.08	}
Seagate		2,677.00				5,664.70	} 7568.1
Microscience				25.80			
Nidec				42.70	83.30	135.10	200.00
Mitsubishi Chemicals			5.54	26.11	207.01	403.47	535.82
Tormedia					6.23	107.95	196.25
Ministor			1.24	6.48			
Integral Peripherals					9.00	28.30	
Quantum (MKE)						1,334.10	1,973.20
Unimagnetics				31.40	38.20	41.20	
Micropolis						US$213	
IBM Peripherals							
Hoya							

Annex A

Highlights of Findings from Analysis of Sample Surveys of HDD Suppliers in Singapore and Penang

To provide additional empirical evidence on the nature of the supplier base established in Singapore and its relationships with the HDD majors, we conducted a structured questionnaire survey of a sample of supplier firms in Singapore in 1997. The results are compared to a similar survey conducted by Haggard, Lim and Ong(1998) in Penang. A total of 13 and 15 valid responses were obtained from the Singapore and Penang survey respectively. The key findings from these two surveys are given in Annex Tables 1 to 21 respectively.

Composition of Sampled Firms

There are some notable differences in the composition of the supplier firms covered in the two locations (Table 1 and 2). For example, while all the supplier firms in Singapore are local-majority owned, only 6 out of the 15 firms covered in the Penang survey are local-majority owned. Moreover, while 3 (20%) of the suppliers in Penang are in disk media/substrate processing, none is covered in Singapore, which has a higher proportion in precision engineering. Such differences in the composition of supplier firms between the two locations suggests that any overall comparison between the two may be biased by sectoral differences. Nevertheless, we believe that the sample compositions are actually fairly representative of the overall supplier bases in the two locations. Consequently, we believe that the differences found among the sampled firms between the two locations do reflect fairly well the actual overall differences between the supplier bases in the two locations.

Differences in Origins of Suppliers

On the whole, the characteristics of suppliers in Singapore clearly stand out in comparison with the suppliers in Penang. First of all, the Singaporean suppliers have been engaged in supplying the HDD industry much longer than their Penang counterpart (10.8 years vs. 3.3 years, Table 4). Secondly, the suppliers in Singapore are more diversified than their Penang counterparts in terms of number of HDD customers being served (Table 5). Thirdly, while a majority of Singaporean suppliers established their first sales to HDD customers through their own marketing efforts in Singapore, a majority of Penang suppliers are replicated transplants of relationships established elsewhere (including Singapore) (Table 6). It is also interesting to note that government recommendation accounted for at least 2 of the first sale to HDD by the suppliers, vs. none in the case of Penang. (It is also likely that one or more of the three cases where the suppliers were sought out by the HDD buyers may also have been the result of a government recommendation.)

Differences in Relationships with HDD Customers

The Singaporean suppliers also differ significantly from their Penang counterparts in terms of the nature of the relationships that they have established with their HDD buyers. A higher proportion of Singaporean suppliers reported having closer, longer-term supplier-buyer relationships with their HDD customers than their Penang counterpart (Table 7). In their interaction with HDD customers, the Singaporean suppliers also reported higher extent of involvement in activities such as new product ramp-up and planning, product modification and improvement, assembly process changes, and production scheduling and planning (Table 9). Moreover, while both groups of suppliers stressed quality and price as the two most important competitive factors, the gap between the two is wider in the case of Singaporean suppliers, which also reported significantly greater importance of responsiveness/flexibility to changing customer demands (Table 8). Finally, a higher proportion of Singaporean supplier firms engage in more frequent interactions with their customers, across a wide range of activities from pre-qualification for job-order to debugging processes for production ramp-up and joint product development (Table 14).

Together, these differences suggest that Singaporean suppliers have established a more sophisticated form of supplier-buyer relationship involving a higher degree of interaction and mutual dependency.

Differences in Technological Capabilities and Learning Mechanisms

Singaporean supplier firms also appear to have developed their own technological capabilities to a higher degree than the Penang suppliers; a larger percentage of the former engage in R&D or were certified for ISO9000 compliance (Table 15). They spent on average 1.4% of their sales on R&D and 5% of their payroll on training; these figures are likely to be higher than for Penang, although comparable figures are not available for the latter as few companies provided the relevant information.

Because of their higher levels of technological capabilities, Singaporean firms appear to have progressed to more advanced forms of technological learning through their supplier-buyer relationships with their HDD customers than their Penang counterparts. In particular, the three most frequently cited modes of acquisition of technological capabilities cited by the Singaporean suppliers involve learning from customer specification, learning by doing and own R&D, whereas the Penang supplier firms still rely most significantly on technology transfer from parent/associate companies, technology transfer from customers and recruiting experienced technical staff (Table 11 and 12).

The above findings are consistent with an alternative indicator that uses the typology of forms of technological learning through supplier-buyer relationships, which distinguishes the direct technology transfer mechanisms from the indirect inducement mechanisms (Wong, 1992). Singaporean suppliers appear to leverage their HDD customers more for transfer of product technological know-how than for process know-how, and they exhibited a higher propensity of learning through the inducement effects than the Penang suppliers (Table 10).

Differences in Host Public Policy Environments

Significant differences in the public policy environment between Singapore and Penang are also found from the survey. Firstly, a larger percentage of Singaporean suppliers (8 out of 13 or over 60%) have established relationships with local universities and research institutes than their Penang counterparts (just 2 out of 15) (Table 16).

Secondly, a larger proportion of Singaporean supplier firms reported that they benefited from government assistance schemes than their Penang counterparts; moreover, the former reported a much broader array of assistance schemes than the latter. In particular, R&D and innovation investment incentives, personnel training, technical assistance schemes and industry upgrading schemes were used by sizable proportions of Singaporean firms, but none were reported by their Malaysian counterparts (Table 17 and 18). [Note: 100% of Penang firms reported that they utilized the Human Resource Development Fund (HRDF) for manpower training. A similar question is not asked in the Singapore survey, but it is virtually certain that 100% of them utilized the Skills Development Fund from which the HRDF was copied.]

Thirdly, while just one Penang-based supplier firm (7%) indicated that they were satisfied with public policies towards the industry, the proportion was over 46% in the case of Singapore. More than half of supplier firms in Penang were dissatisfied, vs. less than one-quarter in Singapore (Table 19).

Last, but not least, the differences in host environment are also revealed from the list of key business concerns voiced by the respondent firms in the two locations (Table 20). While a large proportion of both Singapore and Penang suppliers were concerned with labor shortage and high/rising wages (Singapore more so), the proportion of firms concerned with productivity level was higher in the case of Penang. Moreover, some of the Singaporean firms are becoming concerned with issues such as investment in advanced technology, diversification from dependence on HDD and learning to manage internationalization, issues which have apparently not been confronted by the Penang firms yet. Indeed, while all the Singaporean firms have established overseas sales/services and 85% have established overseas manufacturing operations, the proportion was much lower (one-third) among the local firms in Penang (Table 21).

Annex Tables on HDD Supplier Surveys in Singapore and Penang

Table 1 Ownership of Supplier Firms Surveyed

Ownership Status	Singapore	Penang
foreign-majority	0 (0%)	9 (60%)
local-majority	13 (100%)	6 (40%)
Total	13 (100%)	15 (100%)

Table 2 Composition of Supplier Firms Surveyed

Main Activity of Supplier Firms	No. in Singapore(%)	No. in Penang (%)
Precision engineering	8 (61.5%)	6 (40.0%)
PCBA/FCA	2 (15.4%)	5 (33.3%)
plant design and engineering services	2 (15.4%)	0
Electronic components	1 (7.7%)	0
disk media & substrates processing	0	3 (20.0%)
Assembly equipment & machinery	0	1 (6.7%)
Total	13 (100%)	15 (100%)

Table 3 Degree of Dependence on HDD customers

Extent of sales to HDD industry	Singapore (n=13)	Penang(n=14)
75-100%	4	5
50-74%	2	2
25-49%	3	2
<25%	4	5
Total	13	14

Table 4 Average Length of Relationship with Key HDD customers

Singapore (n=11)	10.8 years
Penang (n=13)	3.3 years

Table 5 Average number of HDD customers

Singapore (n=10)	3.6
Penang (n= 12)	2.3

Table 6 How did firm get first sales from a HDD customer

	Singapore	Penang
Transplanted relationship with customer at other locations	0	8
Business and other association	0	3
sought out by HDD customer	3	1
offered the order by previous HDD employer	0	1
Recommendation by government agency	2	0
direct marketing/bidding	8	2
Total	13	15

Table 7 Nature of Relationship with Key HDD Customer

Relationship is based…	**Singapore (n=12)**	**Penang (n=14)**
solely on ability to meet price and delivery requirements on an order basis; customer does not hesitate to switch suppliers if a better one is found	0	0
mainly on ability to meet price and delivery performance requirement of customer but attempts are made by the customer to foster a longer term relationship beyond individual orders	7 (58.3%)	9 (64.3%)
on long-term mutual gain, customer is unlikely to switch suppliers unless there are persistent shortfalls in performance over time	5 (41.7%)	5 (35.7%)
Total	12	14

Table 8 Relative Importance of Competitive Factors (Score = 3 if ranked most important, 2 if ranked second, 1 if ranked third, zero if not ranked)

Factors	Singapore (n=12)	Penang (n=9)
Quality	2.2	2.0
Price	1.6	1.8
Delivery time	0.5	0.8
Delivery reliability	0.8	0.7
Responsiveness/flexibility to changing customer demands	1.1	0.6
Technological capability/ process reliability	0.1	0.6

(note: some respondents rank more than one factor equally, while some respondents rank less than 3 factors)

Table 9 Extent of Involvement of Suppliers by Key HDD customers (1= "no involvement", 5 = "significant involvement")

Activity	Singapore (number of firms =12)	Penang (number of firms=1
Product design specification	3.7	3.5
Material specification	3.6	3.6
New product ramp-up and planning	4.4	3.4
Product modification and improvement	4.2	3.5
Assembly process changes	4.1	3.4
Relocation of existing activities to another country	3.9	2.5
Production scheduling and planning	4.0	3.4

Table 10 Extent to which HDD customers have helped in technological upgrading (Scale 1=”little”, 5=”substantial”)

Technological upgrading process	Singapore (number of firms = 13)	Penang (number of firms=1
Direct technology transfer		
product technology know-how	3.4	3.1
process technology know-how	2.7	3.1
Indirect inducement		
Providing the opportunity to learn and observe	4.2	3.4
Reducing the risk of investing in new technology by providing orders	3.3	n.a.

Table 11 Top five most important sources of technology acquisition by supplier firms to HDD assemblers, Singapore

Now	5-years ago
learning from customers’ specification [9]	learning from customers’ specification [9]
learning by doing [9]	technology transfer/technical assistance from customers [8]
own R&D [8]	learning from equipment suppliers and vendors [7]
learning from equipment suppliers and vendors [6]	learning by doing [6]
Technology transfer/technical assistance from customers [6]	recruiting experienced technical staff from other companies [6]

Table 12 Top five most important sources of technology acquisition by supplier firms to HDD assemblers, Penang

Now
Technology transfer/technical assistance from parent or associate company [9]
Technology transfer/technical assistance from customer [8]
own R&D [6]
recruiting experienced technical staff from other companies [6]
learning from customer specification [6]

Table 13 Extent of Customization of production processes (1=no customization, 5=high customization)

Extent of customization of production process…	Singapore	Penang
to HDD customer vs. non-HDD customer	3.7 [10]	3.9 [9]
to each HDD customer	3.3 [6]	3.0 [3]
from one order to another from the same customer	3.6 [8]	3.8 [9]

Table 14 Extent of Interaction with Customers

	Singapore (n=13)		Penang (n=15)	
	less than monthly	monthly or weekly	less than monthly	monthly or weekly
To pre-qualify for a job order	9	4	13	2
To improve product design for manufacturability	10	1	14	1
To respond to product specification modification & engineering changes	9	4	14	1
To qualify/assure/ improve/debug production process in the ramp-up stage for new products	8	5	13	2
To conduct joint R&D/product development	6	2	5	1

Table 15 Indicators of technological intensity of supplier firms

	Singapore		Penang	
Technological intensity indicators	**Now**	**5 years ago**	**Now**	**5 years ago**
R&D expenditure as % of revenue	1.4%	0.3%	n.a.	n.a.
Training expenditure as % of payroll	4.8%	3.5%	n.a.	n.a.
% of firms with ISO9000 qualification	77%	38%	50.0% [14]	n.a.

Table 16 Relationships of supplier firms to local universities/public research institutes

	Singapore (n=13)	Penang (n=15)
% of firms indicating existence of relationships with local universities or public research institutes	61.5%	13.3%
Importance of relationship to firm (scale 1=not important, 5=very important)		
Access to new product technology	1.9	n.a.
Access to new process technology	3.7	n.a.
Access to new operations management practice	2.1	n.a.
Access to information on new technology trends	3.6	n.a

Table 17 Extent of Assistance Received by Supplier Firms in Singapore from Public Policies and Programs (n=13)

Type of assistance	**% of firms receiving**
Tax incentives for	
Investment in R&D and innovation	23.1
Acquisition of capital equipment	61.5
Depreciation of capital equipment	53.8
Personnel training/hiring	46.2
land acquisition and/or use	n.a.
overall tax relief	30.8
Technical assistance/subsidy schemes	
Small Industry Technical Assistance Scheme	69.2
Research incentive scheme (RDAS, PDAS, RISC)	30.8
Software development assistance Scheme	0.0
Innovative development assistance Scheme	23.1
Participation in LIUP	38.5

Table 18 Extent of Assistance Received by Supplier Firms in Penang from Public Policies and Programs (n=15)

forms of Assistance Received	No. of firms (%)
Pioneer Status	5 (33.3%)
Reinvestment Allowance	1 (6.7%)
Overall Tax Relief	1 (6.7%)

Table 19 Satisfaction with current public policies/assistance programs towards industry

	Singapore (n=13)	Penang (n=15)
Yes	6 (46.2%)	1 (6.7%)
No comment/Missing	4 (30.8%)	6 (40.0%)
No	3 (23.1%)	8 (53.3%)
Total	13 (100.0%)	15 (100.0%)

Table 20 Major Business Concerns Cited by Respondent Firms

	Singapore (n=13)	Penang (n= 13)
Labor shortage	8	7
High/rising wages	4	2
Productivity level	2	5
Infrastructure-related	0	2
Withdrawal of GSP	0	1
General educational system	0	1
Managing internationalization	3	0
Need to diversify from HDD dependence	4	0
Need to invest in advanced technology	3	1

Table 21 Extent of Internationalization of Supplier Firms in Singapore

% of firms with overseas operations in:	Singapore (n=13)	Penang (local firms only, n=6)
Manufacturing	11 (84.6%)	2 (33.3%)
sales and services	13 (100.0%)	2 (33.3%)