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Inter-Organizational Knowledge Outsourcing: What Permits Small Taiwanese Firms to Compete in the Computer Industry?

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A PUZZLE

This paper addresses a *puzzle* related to *firm size* and *competition*. There is a broad consensus that only large, diversified multinational enterprises can compete in industries that combine high knowledge-intensity and a high degree of internationalization[1]. Small firms, by definition, have limited resources and capabilities and are unlikely to possess substantial ownership advantages. They are obviously constrained in their capacity for knowledge creation. They also have a limited capacity to influence pricing and shape the development of markets, market structure, and technological change.

The disadvantages of small size for firms are compounded if they come, like in the case of Taiwan, from a small country. Small nations are confronted with a *vicious circle of size-related disadvantages*[2]: i) The small domestic market places tight restrictions on the ability to function as a buffer against heavy fluctuations in international demand; ii) It constrains the development of sophisticated "lead users"[3] that could stimulate innovation; iii) It also limits the scope for technological spill-overs[4]; and iv) the limited size of the national knowledge and capital base restricts the choice of industries in which such small nations might successfully specialize.

It would thus seem self-evident that small firms from a small country are ill-equipped to compete in the knowledge-intensive and highly globalized computer industry[5]. Taiwan's experience however tells a different story: Small-and-medium-sized enterprises (SMEs) have been the main carriers of its rapid development. Despite the dominance of SMEs, Taiwan today has the most broadly based computer industry in Asia outside of Japan. Taiwanese computer firms, almost without exception, have started out small and from very humble origins; while many of them failed, a significant number were able to grow and to establish themselves as world-class suppliers for a variety of computer-related products, key components and knowledge-intensive services. The dominance of small firms has obviously not prevented this country from becoming a

[1] For concise statements of this consensus position, see Hymer, 1960/1976, Caves, 1982; the last chapter in Chandler, 1990, and Dunning, 1993.

[2] Important contributions are Walsh, 1987; Freeman and Lundvall (eds.), 1988; and Maskell, 1996.

[3] Von Hippel defines "lead users of a novel or enhanced product, process, or service" as those that "...face needs that will be general in the market place, but...(who) face them months or years before the bulk of that marketplace encounters them..." and who will "... benefit significantly by obtaining a solution to those needs." (Von Hippel, 1988, p.107)

[4] Technological spill-overs are assumed to be mainly domestically generated by innovation theorists (e.g., Lundvall, 1992 and Nelson, 1992) as well as by "new growth" theorists (e.g., Grossman and Helpman, 1991 and 1993). If this is so, then large countries will benefit more from an investment in R&D than smaller countries, where some of the spill-overs of R&D are likely to benefit its trading partners. (Zander and Kogut, 1995)

[5] The impact of knowledge intensity and globalization on firm organization and competitive dynamics in the electronics industry is analyzed in Richardson, 1997; Bresnahan and Malerba, 1997; Langlois, 1992; Langlois and Steinmueller, 1997; and Ernst 1997 b and 1998b. For an early analysis, see Ernst, 1983; and Ernst and O`Connor, 1992.

successful competitor in an industry that requires a broad range of fairly demanding technological and organizational capabilities.

The key to this puzzle, we argue, is *knowledge outsourcing* through a variety of *inter-organizational linkages*. Government policies undoubtedly facilitated the initial market entry of small firms and their continuous upgrading[6]. Of equal importance however are *innovations* in *firm organization* related to the *creation of knowledge*. This is in line with the evolutionary, resource-based theory of the firm - Edith Penrose´s observation that "... a firm´s rate of growth is limited by the growth of knowledge within it." (1959/95, Foreword, 3d edition, pages XVI and XVII) has drastically changed our perceptions of how firms develop and compete[7]. Yet, much of the literature on industrial organization and the theory of the firm is characterized by an *internalist bias*[8] - it neglects that knowledge creation within the firm requires interaction with other firms and organizations[9]. *Cross-organizational coordination of knowledge creation* thus becomes of critical importance.[10]

A novel contribution of this paper is its focus on *inter-organizational knowledge linkages* with other firms and organizations. We show how strong ties with large Taiwanese business groups as well as with public institutions have broadened the scope for learning and knowledge creation in Taiwanese computer companies. A second important contribution is that the analysis is extended beyond national boundaries, highlighting the importance of *international* knowledge linkages. We trace the *co-evolution* of *inter-organizational* and *international* knowledge linkages, and show how this has helped small Taiwanese firms to overcome some of their size-related disadvantages. Common to all of these different arrangements is an attempt to *complement* the *speed* and *flexibility* of smaller firms with the advantages of *scale* and *scope* that normally only large firms can reap.

In contrast to Hobday (1995), and in line with Wong (1999), we also emphasize the *diversity* of such linkages and their *non-linear evolutionary* character. International

[6] Industrial development policies on their own, however, are insufficient to explain Taiwan's success. This is where I differ from Robert Wade´s otherwise extremely stimulating analysis (Wade, 1990) and other more recent analyses with a statist bias.

[7] Other seminal contributions include Richardson 1960/1990; Nelson and Winter, 1982; and Nonaka and Takeuchi, 1995.

[8] Two versions of the *internalist* bias can be distinguished. Teece (1998: 148) highlights a focus on internal *hierarchical control*: "Economists, as well as many organization theorists, have traditionally thought of firms as islands of hierarchical control embedded in a market structure and interacting with each other through the price mechanism." A second version of the internalist bias relates specifically to *innovation*: capability-based theories of the firm have focused primarily on the *internal* accumulation of knowledge and skills which underpins its productive activity (Coombs and Metcalfe, 1998).

[9] Coombs and Metcalfe (1998:3) have convincingly argued that the "… creation of new capabilities is increasingly taking place through the *combination of the capabilities of several firms and research organizations*."

[10] This is in line with population level learning theory (Miner and Haunschild, 1995) which shows that organizational learning depends in important ways on the interaction of organizations, as opposed to feedback from trial and error events inside the organization.

linkages include a variety of ties with sales, manufacturing, and engineering support affiliates of foreign firms; they also include different forms and trajectories of integration into global production networks (GPN) of American and Japanese electronics firms. Taiwanese firms typically have relied on *concurrent* knowledge outsourcing: they have pursued different approaches in parallel, rather than concentrating exclusively on one particular linkage.

Part I of this paper describes Taiwan´s achievements in the computer industry, in terms of its accumulated capabilities. The dominance of SMEs and their role as a source of flexibility is documented in part II. Part III describes policy innovations that have enabled small Taiwanese firms to get onto the virtuous circle of co-evolving inter-organizational and international knowledge linkages. The catalytic role of inward FDI is highlighted in part IV. In part V, we inquire how knowledge creation in Taiwanese computer companies has benefited from knowledge outsourcing through participation in global production networks. Finally, in part VI, we demonstrate how such international linkages have been complemented by evolving domestic inter-organizational linkages.

I. TAIWAN´S ACHIEVEMENTS: A BROAD RANGE OF CAPABILITIES[11]

Over the last decade, Taiwan has established itself as a world-class supply source for a variety of electronic *hardware* products. It is the world's largest supplier of computer monitors, motherboards, switching power supplies, mouse devices, keyboards, scanners and a variety of add-on cards. Almost 60 percent of the world's desktop PCs were either made in Taiwan or contained a motherboard made by a Taiwanese company. Since 1994, Taiwan also has become the world's largest manufacturer of notebook PCs. Most of these computers are sold to American and Japanese computer companies which re-sell them under their own logo, but 70 percent of the computers sold under such OEM arrangements have been designed by Taiwanese companies, indicating significantly improved design capabilities.

Progress has been equally impressive in the field of electronic components. Taiwan today has hundreds of passive component makers that have established a strong position relative to leading Japanese and US competitors. Taiwanese firms have also improved their position in the capital-intensive mass production of precision components, such as large-scale CRT picture tubes for computer monitors and sophisticated display devices for laptop computers. The same is true for integrated circuits, where Taiwanese producers have a better balanced product portfolio than the Korean chaebol which are heavily reliant on the highly volatile DRAM market segment (Ernst, 1998a and 2000b).[12]

[11] If not indicated otherwise, data on Taiwan´s computer industry are courtesy of the Market Intelligence Center of the Institute for Information Industry (III), Taipei.

[12] The island`s chipmakers now account for roughly 7% of the world DRAM market. Their share however rises to 12%, once outsourcing to Japanese chipmakers is taken into account. A large share of this production are shipments to Taiwanese PC vendors and their global OEM customers, which are less vulnerable to heavy price fluctuations. In addition, Taiwan's semiconductor industry has developed a strong position in higher value-added devices, like chip sets, static RAM memories, mask ROMs, and EPROMs. Taiwan also is home to the world's leading silicon foundry, TSMC, a company that is able to produce

Two recent structural changes show how Taiwanese firms have upgraded their capabilities: a rapid diversification beyond hard core PC-related products into a variety of complementary, high-growth market segments, some of which display considerably higher profit margins; and a shift from stand-alone manufacturing services to integrated service packages that cover a wide range of value chain activities, including higher value-added support services. *Diversification* is evident in three areas: the development of PC network products[13], especially modems and network interface cards; multimedia accessories, such as CD-ROM drives and add-on cards[14], and a variety of information services industries, such as multimedia software, system integration, turnkey systems, and network services. These activities owe their existence to the convergence of previously separated technologies used for computing, communicating and digital consumer applications, and require the capacity to combine various strands of technology to generate new applications and markets.

Taiwanese firms have also developed a capacity to provide a *package* of services across a wide range of value chain activities, which has helped them to sustain their position as preferred OEM suppliers. With the exception of R&D and marketing, practically all other stages of the value chain can now be performed by Taiwan's OEM contractors. Moreover, Taiwanese firms are beginning to shoulder essential *coordination* functions for the *global supply chain* management of their OEM customers.

Two characteristic examples of these processes of diversification and the provision of integrated service capabilities are scanners and turnkey production arrangements. Scanner production demands optical, mechanical and electronic technologies and capabilities. Taiwan has accumulated expertise in all three, and has become the world's largest supplier of scanners. With a firm grip on all stages of the value chain, from R&D and production to marketing and after-sales service, Taiwan is positioned to defend its leadership position as a "one-stop shopping center" for scanners.

A second example is the spread of *turnkey production arrangements* in the PC industry. Compaq for instance has out-sourced all stages of the value chain except marketing to Mitac International: the Taiwanese company is responsible for the design and development of new products, as well as for manufacturing, transport and after-sales services at its manufacturing facilities in Taiwan, China, Britain, Australia and the US. For Compaq, Mitac's greatest attraction is its network of plants and sales subsidiaries located in most of the world's key computer markets.

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leading-edge ICs on very short production cycles both for major international semiconductor firms and smaller design firms.

[13] "PC network products" are defined as "products that are used for LANs (Local Area Networks), PSTN (Public Switched Tellephone Network), ISDN (Integrated Services Digital Network), ASDL (Asymmetric Digital Subscriber Loop) and cable modems. Main products include "network interface cards, hubs, bridging switches, modems and routers."

[14] Add-on cards include sound, video and graphics cards. Of these, video cards display higher-than-average profit margins.

Taiwan's achievements would be impressive for any country; they are even more impressive for a small, densely populated island. With a population of about 21 million people, roughly half the size of South Korea, Taiwan lacked a large and sophisticated domestic market, specialized capabilities and support industries, and the science and technology infrastructure necessary for developing a broad set of electronics products. From the outset, Taiwan's PC industry depended heavily on international markets and access to foreign technology. Penetrating foreign markets and absorbing imported technology, however, requires conscious efforts to develop a variety of domestic resources and capabilities through deliberate knowledge creation management.

II. THE DOMINANCE OF SMEs

There is a rich body of research, based on the assumptions of evolutionary economics, that specifies what type of capabilities are required and how the development of such capabilities affects firm organization (e.g., Teece, 1998; Malerba and Orsenigo, 1996; and Gerybadze and Reger,1997)[15]. However, much of this literature focuses on large multi-divisional corporations and fails to discuss how small enterprises can develop such capabilities. This reduces its value for a country like Taiwan where SMEs have been the main carriers of economic development and remain important today. In 1993, SMEs accounted for 96 percent of the total number of companies, 69 percent of total employment and 55 percent of Taiwan's manufactured exports (Chen, Tain-Jy et al, 1995). Taiwan today is home to more than 4,000 electronics firms that produce a broad mix of PC-related products and electronic components. Almost all of these companies started out as small enterprises.

A source of flexibility

How did Taiwanese firms succeed in the computer industry? The answer lies in the fundamental characteristics of an industry in which high volatility and uncertainty put a premium on flexibility and the capacity to adjust to abrupt and frequently unexpected changes in demand and technology. Small firm size can foster such flexibility[16] . By combining incremental product innovation with fast speed-to-market, Taiwanese firms have been able to establish a strong international market position relatively early in the product cycle.

The primary source of this flexibility appears to be the specific organization of the *domestic supply base* in Taiwan, especially for parts and components. Two main features of this domestic supply base have contributed to the flexibility of Taiwanese producers, the first being an extreme form of *specialization*. By engaging in single tasks and by producing, purchasing and selling in small lots, subcontractors avoid heavy fixed capital costs. This, in turn, makes it relatively easy to shift production at relatively short notice, and with a minimum of costs. The second feature is an *organizational innovation* that

[15] For an application of this theoretical approach to research on developing countries, see Ernst, Mytelka and Ganiatsos, 1998, and Ernst and Lundvall, 1997.

[16] For the underlying argument, see Acs and Audretsch,1992. For a critical assessment, see Harrison, 1994.

helps to avoid possible disadvantages of specialization. Andersen (1996) has recently provided an interesting theoretical explanation why excessive specialization may constrain innovation[17]. The solution to this dilemma is the establishment of tight linkages between firms along the supply chain that enhance the prospects for inter-organizational knowledge creation, for instance between end product manufacturers and component suppliers.

Taiwan's computer industry has developed a peculiar *network* structure of *multiple, volatile* and *short-term* links that involve only limited financial and technology transfers. Spot-market transactions play an important role, but so do "temporary spider web" arrangements that are assembled for the duration of a particular job.[18] Taiwan's computer industry thus displays an extreme form of open and volatile production networks, arguably even more so than the highly flexible production networks that characterize California's Silicon Valley (e.g., Saxenian, 1994, and Luethje, 1999). Firms maximize the number of jobs in order to compensate for the razor-thin profit margins; as a result, they avoid being locked into a particular production network. Domestic supplier networks thus have been highly *flexible* and capable of *rapid change*, but *short-lived* and *foot-loose*.

Capability requirements

If flexibility constitutes one prerequisite for Taiwan's competitive success in computers, economies of scale and scope and speed-to-market have been of equal importance.[19] Entry barriers have increased for those stages of the value chain which are of critical importance for competitive success, including particularly component manufacturing where production-related scale economies remain important. But the epicenter of competition has shifted beyond manufacturing to R&D and other forms of intangible investment required to complement price competition with product differentiation and speed-to-market. Only those companies that are able to get the right product to the highest volume segment of the market at the right time can survive. Being late often forces companies out of business.

In sum, what really matters for competitive success are substantial investments in the rapid upgrading of a firm's *technological and organizational capabilities*. How were Taiwanese computer companies able to successfully compete in an industry where size-related advantages are of critical importance? And, more specifically, what kind of organizational innovations have enabled Taiwanese firms to overcome their size-related disadvantages? In order to answer these questions, we need to correct some popular

[17] "While standardization appears to be a necessary consequence of the attempts of economic agents to exploit economies of scale and to avoid dealing with impossible amounts of information, this may also lead to difficulties for innovative activities." Andersen, 1996, p.98.

[18] For details, see Shieh 1990; and Lam and Lee 1993, p.112. Individual firms often bid for contracts beyond their own capacities; once a supplier gets the contract, it calls on other firms, often competitors, to help fill the order.

[19] Chandler, 1990, remains the most authoritative source. Economies of scale and scope in the computer industry are analyzed in Flamm, 1988; Ferguson, 1990; Ernst and O`Connor, 1992; and Ernst, 1997b

misconceptions of the Taiwanese model. This is not an economy characterized by *atomistic* competition. SMEs do play an important role, yet their growth is fostered not by blind market forces, but by a combination of four institutional innovations: government policies that facilitated market entry and upgrading; the catalytic role played by foreign sales and manufacturing affiliates; an early participation in global production networks (GPN); and, finally, evolving strong linkages with large Taiwanese firms and business groups.

III. THE ROLE OF INDUSTRIAL DEVELOPMENT POLICIES

Peculiar features

Policy and institutional innovations played an important catalytic role: they enabled smaller firms to get onto the virtuous circle of co-evolving inter-organizational and international knowledge linkages. Five features have distinguished Taiwan's approach: First, no limits were set on the number of firms within each industry group, with the exception of a few mining and utility industries. Any domestic firm could invest and enjoy the same tax and other privileges. This open policy gave rise to intense domestic competition, and was conducive to a *diversified* industry structure.

Second, the government actively promoted the development and modernization of Taiwan´s SME sector[20]. Government assistance to SMEs included market promotion, management rationalization, cooperation and promoting strategic alliances, loans and upgrading technology and labor training (Ministry of Economic Affairs (MOEA), 1991). Third, there was no discrimination against smaller firms *within* the SME category. Any firm, irrespective of size, could participate and was treated equally. This *neutral* policy was an important foundation for the development of Taiwan´s large pool of vibrant and entrepreneurial SMEs. Fourth, virtually equal treatment was granted to domestic and foreign investment, with the exception of some majority share-holding regulations applicable to foreign firms and strict foreign exchange control regulations governing domestic firms. This balanced policy attracted foreign investment without producing the "crowding-out" that occurred in Singapore, where domestic firms have played a minimal role in the manufacturing sector.[21]

Finally, an important difference that sets apart Taiwan´s industrial policies is that directed credit has played a much less important role, at least until the early 1980s. This can be seen from the high real interest rates for secured loans that Taiwanese firms had to pay during this period.[22] This has changed only since the mid-1980s, when the focus of industrial policy shifted to industrial upgrading. Any firm, irrespective of size, could

[20] The first of these policies, "The Rule for Promotion of Small and Medium Enterprises", was promulgated in 1967 and was subsequently revised several times as Taiwan's SMEs grew.

[21] For an analysis of such crowding-out affects on potential domestic investment in Southeast Asia, see Lim and Pang, 1991.

[22] San Gee (1995), table 4. The real interest rates for secured loans in Taiwan were 14.14%, 9.0 %, 8.05% and 9.7% respectively in 1965, 1970, 1975 and 1985. There was only one exception: in 1980, the rate fell to -2.80, which was primarily due to the second oil crisis in that year. Note that these figures are adjusted for inflationary effects.

participate in industrial promotion programmes, including concessionary credit. In contrast to the Korean government which used its control of the finance sector to direct credit to a handful of chaebol, the Taiwanese government did not try to promote large national champions. The result is that Taiwan`s corporate debt-equity ratio is substantially lower than in Korea[23]: Taiwan´s net debt-equity ratio for 1998 was around 30%, compared with more than 180% for Korea (ING Barings estimate, quoted in The Economist, November 7, 1998, p.13). Taiwan´s smaller companies thus had to rely more on equity markets and corporate retained earnings than on debt.

These peculiar features of industrial policy have shaped firm behavior, especially related to knowledge creation. For instance, Taiwanese firms find it difficult to raise capital for large-scale volume production and must submit investment decisions to short-term financial considerations. As a result, they avoided *homogeneous*, mass-produced products (*commodities*), at least initially, and have focused *differentiated* and design-intensive products and knowledge-intensive *support services*. Taiwanese firms typically emphasize product design and organizational innovations. Their main strength is a quick response to changes in markets and technology through flexible specialization in manufacturing, procurement and marketing. Taiwanese firms have focused much more on *inter-organizational* linkages: *apprentice-type* learning arrangements (Kim, 1997, ibid.) with large firms (both foreign and domestic) has enabled them to upgrade rapidly from relatively simple to increasingly complex forms of international OEM arrangements.[24]

The evolution of Taiwan´s industrial policy

Of equal importance is that Taiwan's policy approach kept evolving in line with the increasing complexity of the industry, and a greater exposure to the international economy. As Taiwan´s computer industry moved up from simple and labor-intensive to more complex products, much more sophisticated policies were required. The main reason is that *entry barriers rise with increasing complexity*: investment thresholds increase and knowledge requirements become more demanding. For small enterprises this implies that they need to have access to *externalities* that would enable them to overcome their size-related disadvantages.[25]

[23] Scitovsky (1986: chart 1) shows that, in most years between 1971 and 1980, Korea´s corporate sector debt to equity was between 310 and 380, while Taiwan´s ratio was much lower between 160 and 180. This is consistent with more recent figures quoted in Fields (1995: table 4-5) which show that in 1985, the debt-equity ratio of Korean manufacturing firms was nearly 350, relative to a ratio of 120 for Taiwan.

[24] There are also downsides to this approach: a lack of access to patient capital has led to a general reluctance of Taiwanese firms to engage in R&D, which arguably explains why they lag behind the chaebol in sectors that are characterized by extremely high investment thresholds and risks, and where the focus primarily is on homogeneous products (like DRAMs and advanced displays).

[25] Externality requirements vary, depending on the market segment and the stage of development of a particular industry. For consumer electronics, they are obviously less demanding than for semiconductors. And within the same product group, i.e. semiconductors, such requirements become much more complex, once the focus shifts from low-end discrete devices for consumer applications to higher-end design-intensive devices.

Greater *exposure* to the *international economy* is a second reason why industrial development policies need to develop over time. Such linkages are necessary to facilitate local capability formation. The increasing complexity of Taiwan's computer industry necessitates more international linkages. These encompass critical imports of key components and capital equipment, and inward FDI. They also involve participation in global production networks (GPN) as well as in a variety of specialized and informal "international peer group" networks that are essential carriers of codified as well as tacit knowledge. Left on their own, small enterprises are ill-equipped to reap the benefits of such international linkages. Again, the market had to be complemented by selective policy interventions that can provide some of the necessary externalities.

This process of change can be traced through Taiwan´s industrial policies that affected the electronics industry. In the early 1960s, the Taiwanese government introduced a series of path-breaking *institutional* and *policy innovations* that were instrumental for establishing the Taiwanese approach to knowledge creation. The first was the statute for technical cooperation, issued in 1962, under which re-investment and the remittance of technology fees accompanying joint ventures were permitted; this had the effect of attracting technology from foreign companies. Much better known is the second innovation: the 1965 Law on the Establishment and Management of Export Processing Zones, first implemented in December 1966 in Kaohsiung, a port city in the south of the island.

Once the policy focus shifted to secondary import substitution, the provision of *external economies* became critical. In 1973, the Industrial Technology Research Institute (ITRI) was established as part of the Ministry of Economic Affairs. ITRI soon moved beyond its original task, which was to develop applied industrial technologies for key components and capital equipment. Equally important tasks now included international technology scanning and acquisition; technology transfer from foreign sources to the domestic SME sector; the development of a nation-wide infrastructure; and the formation of specialized clusters of support industries. ITRI and its specialized divisions[26] also proved a source of "migratory knowledge"[27] for the electronics and computer industries: top researchers and engineers were continuously encouraged to move out into the private sector and to establish innovative start-up companies.[28]

During the 1980s, policy shifted toward *industrial targeting*, especially for the computer industry. In 1980, the government established an industrial park almost entirely devoted to IC manufacturing and computer design, the Hsinchu Science-Based Industrial

[26] Two such divisions have played a critical role for the development of Taiwan´s computer industry: the Electronic Research Service Organization (ERSO) that has focused on the development of key components (especially ICs and LCDs); and the Computer and Communications Research Laboratories (CCL) that focuses on the development of new architectural designs for computers, communications and consumer electronics.

[27] This term was coined by Joseph L. Badaracco Jr. (1991, pages 33-47) who defines it as knowledge, both explicit and tacit, embodied in individuals who migrate from one organization or country to another.

[28] Typical examples of such spin-offs include UMC and Winbond, both of which today have become serious competitors in the integrated circuit industry.

Park (HSIP). Hsinchu offered a large range of fiscal and related investment incentives to attract qualified investment.[29] In turn, companies that have invested in the park must spend a certain proportion of their revenues on R&D and a minimum percentage of their work force must be scientists and engineers. Located close to ITRI and two well-known technology-oriented universities, Hsinchu was able to replicate to some degree a "Silicon Valley"-type informal network that helped to quickly diffuse new technology to Taiwan´s computer industry. The park's close links with Silicon Valley—many of the top executives and engineers of Hsinchu-based companies have worked in the US—facilitated a rapid response to changing technology and international markets.

Overcoming size-related barriers to knowledge creation

Throughout these various policy changes, however, the government maintained a willingness to assist Taiwanese SMEs in overcoming size-related barriers to knowledge creation. In the computer industry, the best example is the case of the notebook PC consortium, established by CCL/ITRI in April 1990.[30] Against strong protest of the leading domestic PC manufacturers, the government refused to set any entry requirements, except an initial entry fee of $48,000 - a sum which even an SME could well afford to pay. The result was that 46 firms became members of this consortium, and thus had equal access to design specifications and prototypes, detailed technical reports for each stage of development, motherboard designs, mass production samples and training classes. This example illustrates a peculiar feature of industrial policy making in Taiwan noted above; the government supports multiple firms in any technology initiative, constantly putting pressure on existing players by bringing in new companies or lower-tier firms. This has created a powerful vehicle for inter-organizational knowledge creation.

Of course, such a government policy to stimulate knowledge creation through market entry and competition comes at a cost. Some of these SMEs later failed due to a lack of sufficient resources and capabilities. Yet, such costs have to be measured against the substantial benefits of these policies, which helped integrate parts of Taiwan's SME sector into the computer industry and generated a critical mass of knowledge. This particular type of industrial policy has also helped to develop Taiwan's flexible and low-cost domestic subcontracting system and its linkages with large domestic and foreign firms. Before we address these network relations, we need to highlight the role played by FDI.

IV. CATALYTIC ROLE OF INWARD FDI

Inward FDI played an important catalytic role for knowledge creation throughout development of Taiwan´s electronics industry. It is important to emphasize the diversity

[29] Liu, 1993, pages 306 and 307. This includes low-interest loans, the right to retain earnings of up to 200 percent of paid-in-capital, a five-year income tax holiday within the first nine years of operation, accelerating depreciation of R&D equipment, and low-cost land.

[30] Interview with Dr. Cheng, Director, CCL (Computer and Communications Laboratories)/ITRI, May 1995. See also the excellent analysis in San Gee, 1995, pages 173 passim.

and evolutionary nature of these contributions. During the critical early phase, FDI exposed Taiwanese workers and managers to new organizational techniques, gradualllly eroding traditional, highly authoritarian and ultimately inefficient management practices. Over time, the need to comply to some minimum international quality standards gave rise to broader learning effects that spilled over to a wide spectrum of local enterprises due to the high turnover in Taiwan´s skilled labor market. A questionnaire survey of 318 Taiwanese electronics firms found that 104 of these companies had high-level managers and engineers with work experience in foreign electronics firms (San Gee, 1990). Of these, roughly 43 percent felt that their working experience with foreign firms was helpful for their management skills, 31 percent said that it was useful for product design and development, and almost 30 percent that it enhanced their capacity to generate market information.

Inward FDI also contributed to the development of local suppliers, at least for domestic market-oriented production. A combination of protection and local content requirements, directed especially at Japanese consumer electronics manufacturers, forced these companies to pull along their main Japanese component suppliers. Together, they systematically groomed local vendors and established a broad range of local supplier networks.

The pioneer was Philips which in 1961 established a large local manufacturing affiliate that produced TV sets, audio equipment, picture tubes and a variety of other related components. Originally, this production facility was geared to the heavily protected local market, but by the mid-1960s, domestic market-oriented production had been supplemented by export platform production. Philips Taiwan is now the exclusive production source for picture tubes for computer monitors within the entire Philips group, and it is among the three largest producers worldwide. Similarly, Philips played a critical role in the successful launching of Taiwan Semiconductor Manufacturing Corporation (TSMC) which today is the world's leading silicon foundry.

In 1962, Matsushita followed suit with a large majority-owned joint venture in Keelung that produced both household appliances and consumer electronics, primarily TV sets. Until the mid-1980s when the group established a network of huge export platform affiliates in Malaysia and Thailand, this was one of Matsushita's main outposts in East Asia. Matsushita´s affiliate has been a *trend-setter* for Taiwan in factory automation (especially for printed circuit board assembly) and for the introduction of fastidious quality control management. Matsushita has also given rise to a broad range of knowledge spill-overs to local companies, through both employment mobility and the formation of local start-up companies. In addition to being an incubator for local suppliers, Matsushita established Matsushita Electric Institute of Technology in 1981. With a work force of around 40 researchers, the institute's main functions are ASIC design and software engineering, especially the development of Chinese-language application programs.

Similar examples can be found for electronic components. Since the late 1960s, most of the leading Japanese component producers set up shop in Taiwan or were engaged in consignment assembly with a growing share of output going to Japan or Japanese affiliates in Asia. These investments played an important catalytic role for knowledge creation in Taiwan´s domestic supplier industry, through intense on-the-job training and employment turnover as well as through close linkages with local subcontractors. More recently, similar developments have occurred in semiconductors: second-tier Japanese DRAM producers like Oki and Mistubishi Electric Corp. (MELCO) have recently concluded important technology licensing, second-sourcing and joint development projects with some of the newly established Taiwanese DRAM producers. The same is now happening for large-size CRT picture tubes.

FDI also acted as a conduit for knowledge transfer in the computer industry. In 1982, DEC established a large integrated affiliate in Taiwan to produce a broad range of products: PC motherboards and chassis, monitors, terminals and printers. Today, DEC Taiwan is the company's largest assembly line for desktop PCs. For Taiwan, DEC´s investment had important positive effects on knowledge creation, through training as well as through the development of local suppliers.

Over time, however, the role of FDI has declined relative to the rapid proliferation of international outsourcing arrangements: these arrangements include subcontracting, consignment assembly and various forms of OEM contracts, and are no longer confined to parts and components but involve high-value added support services such as product customization, product design and production technology.

V. KNOWLEDGE OUTSOURCING THROUGH GLOBAL PRODUCTION NETWORKS

VI.1. Stylised Model

Globalization in the computer industry has culminated in an important organizational innovation, the spread of *global production networks* (GPN) that integrate geographically dispersed, yet concentrated and locally specialized clusters.[31] Their main purpose is to exploit *complementarities* that result from the *systemic* nature of knowledge (Antonelli, 1999). Under certain conditions, these networks may enhance the *migration* of *knowledge across firm boundaries* and *national borders*; they may also improve the opportunities for knowledge sharing and interactive learning *without* co-location (e.g., Ernst, 2000a and 2000b).

It is important to emphasize the *dual* nature of knowledge outsourcing through GPN. Most debates focus on the strategic rationale underlying knowledge outsourcing by large global network flagship companies, and their organizational implications (e.g., Patel

[31] The concept of a *global production network* (GPN) captures the spread of the value chain across firm boundaries and national borders. It may, or may not, involve ownership of equity stakes. For details, see e.g., Ernst, 1994b, 1997a, 1997b, 1998 b, and 2000a. For empirical case studies on diverse GPN in Asia, see Ernst and Ravenhill, 1999, and various chapters in Borrus, Ernst and Haggard (eds.), 2000.

and Pavitt, 1991; and Granstrand et al, 1993.). We look at the other side of the coin: our analysis documents how participation in GPN can facilitate knowledge outsourcing by Taiwanese computer companies that allows them to overcome some of their size-related disadvantages. Three effects of these international linkages can be distinguished: They can act as *conduits* for *knowledge transfers* for state-of-the-art management approaches as well as product and process technologies. At the same time, these linkages can also act as *catalysts* for *knowledge creation* and *capability development within* Taiwanese computer firms. Thirdly, these linkages may also give rise to *joint knowledge creation*, with roughly symmetrical contributions from the global network flagship and from the Taiwanese supplier. It will of course take time for the latter effect to materialize.

A global *network flagship company* breaks down the value chain into a variety of discrete functions and locates them wherever they can be carried out most effectively, where they improve the firm's access to resources and capabilities, and where they are needed to facilitate the penetration of important growth markets. The main purpose is to gain *quick access* to *lower-cost foreign capabilities* that are *complementary* to the firm´s own competencies. Consider a stylized GPN: it combines a large, multi-divisional MNE (the *flagship*), its subsidiaries, affiliates and joint ventures, its suppliers and subcontractors, its distribution channels and value-added resellers, as well as its R&D alliances and a variety of cooperative agreements, such as standards consortia.

The flagship is at the heart of the network: it "… provides … strategic and organizational leadership…beyond the resources that, from an accounting perspective, lie directly under… (its)…management control." (Rugman, 1997: 182) The strategy of the flagship company thus directly affects the growth, the strategic direction and network position of lower-end participants, like Taiwanese computer firms. The *flagship* derives its strength from its *control* over critical resources and capabilities, and from its capacity to *coordinate* transactions between the different network nodes. Both are the sources of its superior capacity for generating economic rents.[32] One critical capability for instance is the intellectual property and knowledge associated with setting, maintaining and continuously upgrading a de facto market standard. This requires perpetual improvements in product features, functionality, performance, cost and quality. It is such "complementary assets" (Teece, 1986) that the flagship increasingly *outsources*.

To mobilize and harness these external capabilities, the *flagship* must accept a certain *dispersion* of the value chain. It also must broaden its capability transfer to individual nodes of its GPN. The (often unintended) result is a creeping *migration of knowledge* to *lower-tier network participants* located abroad, such as Taiwanese suppliers. For the latter, his creates new possibilities for knowledge outsourcing. While in some cases (e.g., "screw-driver" contract assembly), these effects are short-lived, this is

[32] I refer of course to Penrose-type rents. Spender (1998, p.433) demonstrates that "… each type of knowledge can, in principle, be associated with a different kind of rent and competitive advantage." Tacit social knowledge (which Spender calls *collective*) is of critical importance: "The collective knowledge which develops as key players interact under conditions of uncertainty leads to Penrose rents, so labelled because such activity-based learning lies at the core of her theory of the growth of the firm."

not necessarily so. Once local value added increases, the flagship needs to facilitate the diffusion of a variety of *cross-functional*, *knowledge-intensive support services* that are intrinsically linked with production (Ernst, 2000d). The latter include for instance tooling and equipment, benchmarking of productivity, testing, plastic injection molding, process adaptation, product customization, prototyping and ramping-up, and supply chain coordination. Even if these activities do not involve formal R&D, they may still give rise to considerable learning and innovation.

A GPN can create a *virtuous circle* of cross-border knowledge migration for two reasons. *First*, it increases the length of the flagship's supply chain, as well as its logistical complexity. This creates new gaps and interstices that can be addressed by small, specialized suppliers. Over time, they may be able to upgrade their position from simple contract manufacturers to providers of integrated service packages, increasing their benefits from network participation. As indicated in part I, this has already happened for some Taiwanese suppliers.

Second, once this happens, this creates further pressure for a continuous migration of knowledge: to the degree that suppliers successfully upgrade their knowledge base, this provides an additional incentive for the network flagship to tap into such external capabilities. In turn, this requires that the flagship transfers more knowledge-intensive, higher value-added support activities to individual network nodes, possibly including engineering, product and process development, as well as supply chain coordination. This not only reflects the *outsourcing* logic that we have discussed before. Equally important are the increasingly demanding time management requirements: in the computer industry, product-life-cycles (PLC) have been cut to the bare minimum; only those firms succeed that are first in shipping new products, and that can introduce them simultaneously in all major growth markets. This implies that overseas production must now frequently occur soon after or in parallel with the launching of new products. Ramping-up production at such speed is only possible if key design information is shared more freely between the parent company and its overseas affiliates and suppliers. In short, speed-to-market requires that engineers across the different nodes of an GPN are plugged into the *flagship* company´s design debates (both on-line and face-to-face) on a regular basis. For Taiwanese computer companies, this broadens their scope for knowledge outsourcing.

Taiwan's participation in global production networks

A few examples can illustrate how participation in GPN has created new opportunities for *knowledge outsourcing* by Taiwanese computer firms. We focus on the most important of such linkages, i.e. manufacturing on an OEM basis.[33] Taiwan´s

[33] Definitions of what constitutes an *OEM* (original equipment manufacturing) contract keep changing. Probably the most widely accepted definition refers to arrangements between a brand name company (the network flagship) and the contractor (the supplier) where the *customer provides detailed technical blueprints and most of the components to allow the contractor to produce according to specifications.* Using this definition of OEM arrangements, we can then distinguish *ODM* (original design manufacturing) as arrangements where the *contractor is responsible for design and most of the component procurement, with the brand name company retaining exclusive control over marketing.*

involvement in the OEM business has gone through different incarnations, from very simple arrangements to highly complex ones. Each of these stages has given rise to a peculiar pattern of knowledge outsourcing. We demonstrate that these linkages overwhelmingly have served as *conduits* for *knowledge transfers* as well as *catalysts* for *knowledge creation* and *capability development within* Taiwanese computer firms.[34]

Taiwan´s entry as a supplier for the international computer industry dates back to the mid-1960s. The breakthrough came in 1966 when IBM set up its International Procurement Office (IPO) and started to purchase computer parts and components from Taiwan. IBM's demanding procedures for product development, production ramp-up and quality control as well as its grueling requirements for vendor qualification forced Taiwanese firms to radically upgrade their product quality. It also forced them to develop a broad spectrum of capabilities required for manufacturing as well as product design. In the process of qualifying as an IBM supplier, countless Taiwanese firms learned how to improve their input procurement and production control methods in order to cut costs, improve quality and to speed-up product development cycles and delivery. IBM engineers regularly visited Taiwanese suppliers, screened their production facilities and logistics and assisted them to improve their overall efficiency. These visits included countless missions by IBM engineers sent from the US or other affiliates of IBM's global production network.[35]

Being an IBM supplier has been a great asset to many Taiwanese firms: buyers feel that they can trust a supplier who has been able to cope with the stringent IBM procurement requirements. Going through an IBM apprenticeship thus has helped Taiwanese firms to overcome their negative image of unreliability and shoddy quality. It has helped them to win more orders from other foreign computer companies.

Taiwan however had to wait until the early 1980s before it was able to establish itself as a credible OEM supplier. Until then, Japanese firms controlled the higher-end of the international OEM market, and Korean chaebol occupied the lower-end market segments. Two external developments helped to change this situation.[36] The first occurred in 1982 when the Taiwanese government responded to American pressure and declared the cloning of Apple II computers and video games illegal. Taiwanese firms thus moved on to clone IBM PCs, which remained legal. These developments coincided with dramatic changes in the computer industry that created a window of opportunity for low-cost producers (e.g., Ernst and O'Connor, 1992, chapters II and IV). In contrast to mainframe and mini-computers, PC design is based on standard microprocessors and operating systems. As a result, computers became *mass-produced, standardized products (commodities).* Barriers to entry to final assembly are low and the key to success for any

[34] In a future paper, we will discuss under what conditions these linkages will give rise to *joint knowledge creation*.

[35] According to one source at IBM Taiwan, the mother company dispatched over 400 such missions during the 1980s in order to assist Taiwanese suppliers. (Author´s interview at IBM Taiwan)

[36] The following is based on Callon, 1994; Wong Poh Kam, 1995 and author´s interviews in the Taiwanese computer industry since 1987.

"cloning" strategy lies beyond manufacturing. A critical factor is *time-to-market*: the PC vendor needs guaranteed access to reasonably priced key components and the most up-to-date operating system; and its supply base for motherboards and other components must be able to respond fast and flexibly. Coping with the first prerequisite required close links with Intel and Microsoft, while Taiwan's flexible domestic SME supplier base perfectly suited the second prerequisite.

A second external factor facilitated Taiwan´s entry into the international OEM business. In 1987, the US government imposed punitive tariffs of 100 percent on Japanese PCs, both in response to US-Japanese trade conflicts in semiconductors and as a reaction to a perceived violation of COCOM rules by Toshiba.[37] The punitive tariff on Japanese suppliers allowed the Taiwanese to demonstrate to American computer companies that they could replace the Japanese suppliers with good products at good prices, and that they could even deliver more quickly.[38]

Since then major American computer companies have considerably expanded their OEM purchases from Taiwanese sources. IBM for instance sources monitors from Philips Taiwan and Sampo; motherboards from GVC, Elite and Lung Hwa; power supplies from Delta and Sun-Moon-Star and laptops from ASE. Similar arrangements exist for all major American computer companies. Japanese computer companies followed suit during the early 1990s, once their tight grip over their domestic market was challenged by the aggressive price war strategies of American computer companies (Ernst, 1997a).[39]

Evolutionary Aspects: Upgrading Knowledge Outsourcing within the OEM Paradigm

At the beginning, OEM arrangements were very simple, both in terms of the products and the required capabilities. The focus was on low-end desktop PCs and labor-intensive peripherals, like computer mouse and keyboards. The OEM customer provided detailed technical "blueprints" and technical assistance to allow the Taiwanese contractor to produce according to specifications. They also frequently send their engineers to help local manufacturers to meet quality standards. The latter type of knowledge transfer is of particular importance as it involves the more elusive, tacit dimensions of knowledge (Bell and Pavitt, 1993; and Ernst and Lundvall, 1997).

There is a broad consensus that Taiwanese firms were able to reap substantial benefits from this *easy* phase of OEM. For example, in a late 1980s survey of 43

[37] Toshiba`s clandestine sale of a complex numerically controlled machine tool to the Soviet Union, judged to be of high value for arms production, provoked the action.

[38] Although the tariff was removed one year later, it was by then too late for Japanese computer companies to recover their lost share in the rapidly moving OEM market.

[39] NEC for instance gets monitors and motherboards from Tatung and Elite, Fujitsu has relied primarily on OEM supplies from Acer, and Epson, Canon, Hitachi, Sharp and Mitsubishi have all become major OEM customers. Since 1994, Japanese PC manufacturers heavily rely on OEM contracts with Taiwanese firms for notebook computers.

Taiwanese OEM suppliers (27 domestic and 16 foreign invested), roughly 70 percent acknowledged that OEM contracts were useful in transferring production technologies and in acquiring product design capabilities (San Gee, 1990, table 4.1). Yet, these simple forms of OEM also had substantial drawbacks (e.g., Ernst and O´Connor, 1992). Suppliers became "locked into" OEM relationships that hindered independent brand name recognition and marketing channels. Profit margins are thinner in OEM sales than in own brand sales, which in turn makes it difficult for suppliers to muster the capital needed to invest in R&D required for the development of new products.

In response to these draw-backs, a number of Taiwanese computer companies tried to expand their share of *own brand-name manufacturing* (OBM) sales. Yet, the transition to OBM turned out to be difficult, and most companies failed. This is hardly surprising: developing a global brand image is costly and involves extreme risks; it is way beyond the reach of most Taiwanese companies, with the possible exception of some larger companies like Acer. Taiwanese firms are now content to consolidate and upgrade their position as OEM suppliers. After falling throughout most of the early 1990s, the share of OEM/ODM in all Taiwanese computer hardware sales has increased from 66% in 1995 to more than 75% today. In contrast to a widespread perception (e.g., Hobday, 1995), this may not necessarily harm Taiwan´s computer industry. It is in fact possible to argue that successful knowledge outsourcing does not require a *sequential* move from OEM, up to ODM, and then further up to OBM. Instead, Taiwanese suppliers were able to learn and to create knowledge through *concurrent* implementation of these different knowledge outsourcing approaches.

This somewhat counter-intuitive argument can be demonstrated both theoretically and empirically. Drawing on competence-based theories of the firm, Lee and Chen (1998, p.4) demonstrate that "… concentrating in either type of business activity exclusively will not be better than concurrently engaging in both OBM and OEM/ODM businesses". It is through such concurrent and multiple linkages that a *virtuous circle* between knowledge outsourcing and knowledge creation becomes feasible.[40]

Concurrent Knowledge Outsourcing

The example of Acer provides an empirical demonstration of concurrent knowledge outsourcing. The company's involvement in the PC cloning business dates back to 1983, when it was among the first Taiwanese companies to introduce an IBM XT/PC compatible. In the same year, Acer had organized Taiwan's first International Distributor's Meeting, attended by delegates from over 20 countries. Building strong links with foreign distributors and OEM customers subsequently became an important

[40] This reflects the increasing interdependence between design/development and manufacturing that is typical for the computer industry. The more inter-linked they become, the greater will be the opportunities for Taiwanese suppliers to expand their knowledge base through concurrent knowledge outsourcing. In order to capture this important aspect of knowledge creation management, it is necessary to open the black box of OEM, and to distinguish a diversity of such arrangements in terms of their technological capability requirements and their contractual relationships.

priority, complementing Acer's strong domestic roots. In 1988, Acer hired a senior IBM executive to reorganize the company with the explicit goal to transform it into a global competitor. Expectations were running high. IBM was still considered the industry's role model; by copying key features of IBM, Acer expected to speed up its leap-frogging effort. In particular, the idea was to increase the company's vertical integration and to generate a critical mass of proprietary assets through acquisitions that would enable Acer to develop its own brand name image.

This effort failed miserably. The IBM manager assumed that change could be imposed from above by forcing consensus on the local management. Such an aggressive top-down approach ran into stubborn opposition by Acer's managers and engineers, who were used to a substantial amount of decision autonomy. More important however is that Acer simply did not have the resources that are necessary to implement such a strategy. Acer`s acquisitions of innovative, yet financially troubled US computer companies undoubtedly provided access to new knowledge. But this on its own is insufficient - substantial additional resources are required to absorb this new knowledge and to diffuse it within the company. Only then are there realistic chances that acquisitions will act as catalysts for knowledge creation and capability development within the acquiring company.

In the case of Acer however, acquisitions led to high losses - to high a burden to bear for a medium-sized company. The awakening came in 1991 when Acer posted a loss ($23 million) for the first time. Acer's over-ambitious diversification strategy came at the worst possible moment. The PC industry worldwide was swept by a crippling price war, as a result of which almost all companies faced a serious profit squeeze. Taiwan's computer industry was particularly hard hit and went through a major shake-out.

Acer`s response was to consolidate its position as an OEM supplier, and to focus its OBM strategy on non-OECD markets where the market leaders are not present.[41] The goal is to become one of the world´s highest-volume producers of peripheral equipment, key components, sub-assemblies and design services, both for Acer's worldwide computer assembly plants and for global PC brand name leaders.[42] Acer’s strategy now is to leverage its OEM business to generate the necessary financial resources to pursue its OBM strategy and to develop capabilities, especially in design and computer networking.

[41] After an early success in the US market (#5 spot in the multi-media PC market segment during 1995), Acer had to withdraw almost completely as an OBM supplier. While Acer retained its top position in a number of rapidly growing, yet still quite secondary markets like Indonesia, Malaysia, Mexico and South Africa, the overall growth of sales revenues for computers has slowed down and Acer has still not succeeded to expand its OBM market share in Japan and China. These results are simply too meager to support Acer’s ambitious upgrading strategy.

[42] Acer tries to combine the following, not always consistent goals: to establish a credible global brand image for a broad mix of "affordably-priced products"; to improve its ability to market such products quickly and to adapt them in response to changing market requirements; to penetrate secondary markets in Asia, Latin America, and elsewhere in order to gain economies of scale; and to use these countries as a test-ground for refining its globalization strategy.

Knowledge outsourcing through OEM has become an important vehicle for upgrading Acer's internal knowledge base.

Acer's experience is consistent with Chandler`s discussion of the difficulties of overcoming the *first mover* advantages of large multinationals (Chandler, 1990). However, there is also a positive side to it, related to the dynamics of knowledge outsourcing. The story of Acer shows that there is no easy and quick short-cut to success and that leap-frogging is an illusionary concept that should be discarded (e.g., Ernst and O`Connor, 1989, chapter II; and Hobday, 1995). Developing a firm's knowledge base is a time-consuming and laborious process: at each stage of its growth, new barriers arise that require a period of consolidation. The more Acer and other Taiwanese computer companies progress and grow, the more demanding will be the barriers they have to cope with. Developing a global brand image is costly and involves extreme risks. This precludes a frontal attack on the market leaders. Acer´s approach to "attack from the sidelines" and to focus its OBM strategy on non-OECD markets appears to be an appropriate response to this dilemma. Taiwanese computer firms will have to rely for quite some time on concurrent knowledge outsourcing through OEM contracts. Other examples support this view.

Compaq for instance has an interesting arrangement with Inventa, a Taiwanese company that has earned a reputation for innovative notebook design and that has already supplied notebooks on an *original-design-manufacturing* (ODM) basis to Dell and Zenith, an affiliate of the French computer firm Bull. Inventa has only a few hundred employees in Taiwan, with a large share of engineers. Inventa is part of the family-owned Inventec business group that is involved in a wide range of products and services, but is most well-known for calculators and telephones. This provides Inventa with access to low-cost volume production facilities that the group has established in China and Southeast Asia, primarily Malaysia. A second attraction of such networks are the sophisticated quality control procedures characteristic of Inventec´s manufacturing facilities. Inventec made Texas Instrument's calculators for 15 years, and had to cope with TI´s stringent quality requirements. But probably the most important reason for Compaq to link up with Inventa were the company's specialized design capabilities for notebook computers.[43] In order to tap into both sets of capabilities, Compaq had to integrate Inventa into its *product development dialogue*; it also had to share some of its tacit knowledge on *design-for-manufacturing*, and on *global supply chain management*. This provided substantial learning effects for Inventa.

Compaq also provides another example of the increasing complexity of Taiwan´s knowledge outsourcing through OEM. As described in part I, in a recent "*turnkey production"* contract with Mitac, Compaq has out-sourced all stages of the value chain for some of its desktop PCs, except marketing for which it retains sole responsibility.

[43] In 1994, Compaq was only fourth in the notebook market behind IBM, NEC and Toshiba. By using Inventa´s notebook design, Compaq expected to leapfrog the market leaders, without commiting its own limited engineering resources (Wall Street Journal, February 3, 1995, p.B69).

Other global PC brand name leaders have followed Compaq's example.[44] *Turnkey production* arrangements clearly indicate how rapidly OEM relationships have moved beyond production to encompass an increasing variety of knowledge-intensive, high-end support services. The spread of such broad cross-value chain arrangements shows that leading global computer companies are confident that Taiwan´s computer industry is now sufficiently well integrated into the global pool of specialized knowledge to serve as a low-cost, one-stop supply center.

In short, it is possible to proceed to more sophisticated forms of knowledge outsourcing *within* the OEM trajectory. Paradoxically, an *increasing concentration* of the global computer industry has apparently facilitated this process. The top five industry leaders have increased their global market share from roughly 20% during the early 1990s to almost 50%; yet, they are all Taiwan´s OEM clients. Their main strength is the definition of architectural standards and their global brand image. These global market leaders are at the cutting-edge of product development, but they outsource almost everything else. Close interaction with these industry leaders provides Taiwanese computer firms with a constant flow of precious feedback information on product design, new architectural standards, leading-edge production technology, and sophisticated quality control and logistics procedures. Close links with these industry leaders acts as a powerful vehicle for a further strengthening of the learning and innovation capabilities of Taiwanese computer firms.

Of even greater importance is a tendency to extend OEM contracts to comprise an integrated package of higher-end support services, as illustrated in the *turnkey production* contracts of Compaq with Mitac, and of IBM with Acer. This implies that, with the exception of hard-core R&D and strategic marketing, Taiwan's OEM supplier community must shoulder all steps in the production chain and the coordination functions necessary for global supply chain management. A major prerequisite is the capacity to assist foreign OEM customers in the management of their global supply chain. All major global players have drastically rationalized their global supply chain and are moving rapidly toward order-based production. In their choice of OEM suppliers, they demand a capacity for just-in-time delivery: for Taiwanese suppliers, this implies that speed and flexibility of response are critical; Taiwanese suppliers also must establish their own global network of plants and sales affiliates in close proximity to major computer markets. In other words, organizational innovation is of increasing importance and can go a long way in compensating for weaknesses in technological innovation (Pavitt, 1998).

These fundamental changes in OEM relationships are producing a new and somewhat surprising division of labor between large Taiwanese computer majors and SMEs. Large firms appear to rely more on OEM contracts, while SMEs are much more active in ODM. For instance, OEM orders for desktop computers are all concentrated on

[44] An interesting example is IBM which relies on Acer's GPN in developing countries to assemble lower-end IBM desktop and laptop PCs and to distribute and service them. For IBM, Acer´s main attraction is its "global operations", its strong presence in developing countries, and its "ability to tailor its products to each market." The Wall Street Journal, December 6, 1996

a select group of large companies, i.e. Tatung, Acer, DEC Taiwan, FIC and MITAC. The same is true for other scale-sensitive products such as monitors and modems. This sounds counter-intuitive, but OEM contracts come in large orders; they typically generate razor-thin profit margins. Economies of scale and scope are of critical importance, and large firms are better placed to reap such economies. Time and again, we thus find that Chandler's insistence on the continuous importance of scale and scope economies makes perfect sense, even in a fast moving sector like the computer industry (Chandler, 1990). Moreover, only a large firm can avoid becoming overly dependent on one particular customer.

Smaller firms may find it too risky to depend on large OEM contracts, as each of these contracts normally surpasses their maximum production capacity. They prefer to shift to ODM contracts where they have greater chances to sustain a diversified customer base and charge higher prices. This has important implications for Taiwanese-style knowledge creation management. It implies that SMEs are under *greater pressure relative to large Taiwanese firms to improve their design capabilities to become credible niche market players* within the overall OEM market. In short, sophisticated knowledge outsourcing through ODM can help upgrade technological capabilities of SMEs. Many of these SMEs will not succeed, but those that do have good chances to grow and to improve their competitive position.

VI. MANAGING INTER-ORGANIZATIONAL LINKAGES

Successful knowledge outsourcing through international linkages over time has imposed far-reaching changes on the organization of Taiwan´s computer industry, where growing concentration has given rise to a polarization between a few large players (the first-tier OEM suppliers), and a large number of small, lower-tier suppliers. In turn, this has led to important changes in firm organization and management approaches.

Historically, small, family-owned firms have played an important role in the development of Taiwan´s electronics industry. Yet, this from of business organization is now coming under increasing pressure, and appears to be ill-equipped to deal with the new competitive requirements. Family bonds erode, especially when the firm has to move production overseas and loose networks between family-owned SMEs are unable to raise the capital required for increasing fixed investments and R&D outlays. As a result, Taiwanese SMEs had to develop a variety of linkages with third parties and to experiment with new forms of managing inter-organizational linkages. In what follows, we will highlight three peculiar developments: *informal peer group networks*; integration into loose *cross-sectoral* conglomerates; and the development of *sector-specific* business groups.

Informal "peer group" networks

Taiwanese SMEs have always relied heavily on *informal social networks* for access to resources, capabilities and knowledge that they are unable to mobilize on their

own. Over time, the focus of these networks has shifted from labor, capital and basic market information to technological knowledge and brand name recognition. Originally, these networks were restricted to family and kinship relations. They are now rapidly being substituted by *professional* "peer group" networks. This is especially true for the electronics industry where resource and capability requirements are much more demanding than in traditional industries. Due to the heavy brain drain of Taiwanese computer engineers, especially into Silicon Valley, these networks increasingly take on an international dimension.

Informal peer group networks come in a variety of forms. Typically, class mates (especially in elite schools) and former colleagues (especially in foreign affiliates) form tight networks that can be instrumental in the creation of start-up companies. For example, Taiwanese computer firms rely heavily on informal information exchange with former classmates for the generation of tacit knowledge on specific engineering and marketing problems and when they need confidential information on potential partners or competitors. Interviews at Acer for instance showed that even today, when this company has long moved beyond its earlier SME status, senior managers still prefer to contact former teachers or class mates when they have to deal with a specific engineering, marketing or management problem rather than a commercial consulting firm or a technology research institute.

Acer actually has been a master in the formation of such informal networks; much of its success arguably is due to the scope and depth of its peer group linkages. Founded in 1976, the company's first activity was to run a training center for computer engineers. In the first three years, more than 3,000 engineers were trained who later were to occupy important positions in Taiwan´s nascent computer industry. As a result, Acer was able to establish early on an extensive network of social contacts within Taiwan´s computer community. These contacts have become an important asset. Since 1986, Acer Sertek Inc, the company's domestic sales, marketing and service arm, has trained more than 170,000 Taiwanese students in computer use.

Cross-sectoral conglomerates

Over time, linkages with large firms have played an increasingly important role in the development of Taiwan´s SME sector (e.g., San Gee and Wen-jeng Kuo, 1998). They have also facilitated knowledge creation in small firms. Many SMEs are now affiliated with a particular *business group* (Liu, Liu and Wu, 1994). The growing capital requirements and technological complexity that accompanied the rapid industrial transformation of the island produced new forms of business organization. When electronics took over from textiles as the leading industrial sector, this led to an erosion of Taiwan´s traditional form of business organization: the loose networks of family-owned SMEs. In order to retain profitability, family firms were forced to venture across product lines and to move from industries with declining margins, like textiles, to the much more profitable electronics sector. In most cases however they were unable to raise the capital required for increasing fixed investment and R&D: as late as 1992, only 20

percent of a sample of Taiwanese manufacturing firms were engaged in R&D (ibid., p.51).

Attempts to cope with these two conflicting pressures produced a peculiar Taiwanese form of business organization: *cross-sectoral conglomerates*. These are very different from the large, hierarchical conglomerates, the *chaebol*, that are typical of South Korea, but they also differ from the *keiretsu* system that has dominated much of Japan's industry. In Taiwan, conglomerates typically consist of a *loose network* of mostly *medium-sized* companies that produce a variety of products for different markets, with one core company exercising financial control. This type of firm organization reflects the need to *combine* the *scale advantages of large firms* with the *speed* and *flexibility* of *smaller* firms.

The ADI business group provides a typical example. Founded in 1979, the company is run by the Liao Jian-cheng family. From trading and construction it first moved into shoe manufacturing for international mass merchandisers. Around the mid-1980s, the family decided to move into electronics. The breakthrough came in 1993, thanks to big orders from Compaq. Despite success in computer monitors, the owners maintain their diversification strategy. ADI has continued to expand its position in shoe manufacturing, while at the same time investing in a number of new small start-up companies in software, system design, and in a variety of unrelated commercial activities. Such unrelated diversification into new, more knowledge-intensive activities could only work if the mother company was able to orchestrate an effective transfer of knowledge between its different affiliated companies. Much of this knowledge transfer originally was channeled through informal peer group networks discussed before. Yet, continuous upgrading required the development of more formal inter-organizational linkages, which has fostered the development of *sector*-specific business groups.

Sector-specific business groups

The development of sector-specific business groups has been most pronounced in the computer industry. This is hardly surprising, given the critical importance in this industry of economies of scale and scope. But in Taiwan's case, there are two additional reasons why SMEs became integrated into larger business groups: linkages with foreign customers through international subcontracting and OEM arrangements; and linkages with international supply sources, especially for key components. As a result of these linkages, size became essential to secure economies of scale and scope and achieve sufficient bargaining clout with foreign customers and suppliers.

To fulfill an OEM contract, large Taiwanese companies like Tatung, First International Computer (which is part of the Formosa Plastics group), Mitac and Acer rely on hundreds of loosely affiliated domestic suppliers to which they can pass on an endless variety of low-margin, yet quite demanding manufacturing and design tasks. The typical Taiwanese small computer company thus often gets involved with foreign firms only in an *indirect* way; large Taiwanese business groups dominate the direct interface

with foreign customers. To mobilize and harness these external capabilities, the large business groups are forced to accept a creeping migration of knowledge to some of these smaller suppliers. This is especially true for *cross-functional, knowledge-intensive support services* for production.

Over the last few years, the importance of sector-specific business groups has further increased, as Taiwan's computer industry witnessed a rapid increase in *concentration*: the top 10 firms today control roughly 80 percent of total production, and some of the most powerful Taiwanese business groups (Formosa Plastics, HwaHsin, China Steel, YFY Paper) have now also entered the production of key components, like DRAMs, CRTs and displays. The challenge now is to develop an organization that enables them to improve *organizational learning*. For PC manufacturers, the main role model is the *Client-Server* model, used by rapidly growing companies like Acer or Mitac: business units are spun off into independent profit centers, creating a *federation of loosely connected companies* united by four factors: access to *common core technologies*; access to the holding company's *financial* resources; access to its *knowledge base, market intelligence* and *technology scanning* capabilities; and a common *brand name*. This type of organizational innovation makes it possible to keep high value-added operations and core capabilities in Taiwan, while dispersing sales, marketing, procurement, product integration and service operations around the world, in close proximity to the main growth markets.

Each of the different members of a "Client-Server Organization" are separated by product lines and by geographic region, and each operates independently. This allows them to make decisions quickly in response to market changes and to define the market segments where they feel fit for leadership. At the same time, however, all of these businesses have ready access to the lead company`s knowledge base which considerably increases their scope for knowledge creation. One important element of this re-organization is a new approach to overseas PC assembly. Acer provides an example.[45] In order to reduce cost and increase speed-to-market for new products, Acer has established 15 modular assembly sites around the world. Each of these assembly subsidiaries is located close to important markets and performs only very limited activities: it receives PC housings and floppy disk drives by sea, with motherboards flown in directly to ensure delivery of the newest technologies. Central processing units (CPUs), hard drives and memory are sourced locally to fill individual user requirements, and the modular components are assembled quickly according to a standardized procedure. This strategy allows Acer to maintain control over product quality and keep inventory to a minimum, while providing fast assembly of competitively priced PCs that always contain the latest microprocessor generation.

Widely lauded until recently, this management approach is now running into increasing constraints. Two major weaknesses can be identified: First, an *internalist* bias, where a focus on vertical integration *within* the group fails to capture potential benefits

[45] Based on author´s interviews at Acer. Similar approaches have been developed by other leading Taiwanese computer manufacturers like Mitac and FIC.

of global outsourcing that has now become the dominant organizational model in the PC industry (e.g., Sturgeon and Florida, 1999). A second related weakness results from an excessive de-decentralization among different "Client-Server" organization members, which has given rise to over-extended product diversification, constrained the coordination between different value-chain stages, and slowed-down the critically important speed-to-market. Equally important is that a combination of an internalist bias with loose coordination can have quite negative effects on group-wide quality control. An example are Acer`s recent quality image problems in the critical US market.

In short, successful implementation of knowledge outsourcing through inter-organizational linkages requires permanent adaptation in firm strategy and structure. To the degree that key stages of the value chain have moved beyond the boundaries of the firm and across national borders, such adaptation requirements become more demanding and complex.

CONCLUSIONS

This paper has introduced an alternative conceptual framework that centers on the *co-evolution of domestic and international knowledge linkages*. This framework allows us to analyze what permits small firms to compete in globalized high-tech industries. The paper demonstrates that *inter-organizational knowledge outsourcing* is critical for small firms that compete in the computer industry. If well organized and managed, such external knowledge linkages can effectively compensate for some of the original size-related disadvantages of small firms, at least for a certain period of time. The paper however also shows that external linkages are *no substitute for intra-organizational knowledge creation*. This confirms Edith Penrose´s observation that firms cannot grow without developing their own knowledge base.

The paper also emphasizes that inter-organizational knowledge creation is not confined to regional clusters or to the nation state. In industrialized countries, many of these external knowledge linkages are with *domestic* organizations. This is very different for a small developing country. When Taiwan began to enter the computer industry during the late 1970s, domestic linkages did not exist or were at best embryonic. *International* linkages thus were initially of primary importance. This is in line with the findings of research on technological learning in developing countries[46]. Two types of international linkages have been distinguished: inward FDI and the participation of Taiwanese firms in global production networks established by global players. Inward FDI has played an important catalytic role for knowledge creation during the early phase of the development of Taiwan´s electronics industry.

Participation in global production networks has provided an important source of knowledge outsourcing. Manufacturing on an OEM basis has been the most important of

[46] This research has clearly established that successful late industrialization critically depends on the international sourcing of knowledge. Examples include Dahlman, Ross-Larson, and. Westphal, 1987; Bell and Pavitt, 1993; Nelson. and Pack, 1995;Kim Linsu, 1997; Lall, 1990 and 1997; Ernst and Lundvall, 1997; and Ernst, Ganiatsos and Mytelka, 1998.

such linkages. Taiwan´s involvement in the OEM business has gone through different stages. Each of these stages displayed a peculiar pattern of knowledge outsourcing. It started with very simple OEM arrangements that covered low-end desktop PCs and labor-intensive peripherals. In response to their draw-backs, a number of Taiwanese computer companies have tried, during the early 1990s, to expand their share of own brand-name manufacturing (OBM) sales. Most of them failed and are now content to consolidate and upgrade their position as OEM suppliers. The paper demonstrates that, *paradoxically, this increasing reliance on OEM arrangements has had positive effects for knowledge creation in Taiwan´s computer industry*. Contrary to established wisdom, successful knowledge outsourcing does not necessarily require a shift from OEM to OBM.

All of his implies that requirements for knowledge creation have become much more demanding: Taiwan's OEM supplier community must now be able to master all steps in the production chain, with the exception of hard-core R&D and strategic marketing. In addition, Taiwanese OEM suppliers must be able to perform for their customers *coordination* functions that are necessary for global supply chain management. Most importantly, this implies a move away from informal social networks to a more formalized network organization, based on information technology, especially enterprise resource planning (ERP) software. It also requires that Taiwanese firms gradually move beyond their internalist bias, and increase their own global outsourcing linkages.

The paper also emphasizes that benefits from international linkages do not come automatically. Of critical importance are *government policies* that have created a set of innovative institutions and incentives conducive for inter-organizational knowledge creation. Of equal importance were a variety of *domestic linkages* that range from informal peer group networks to a variety of innovations in firm organization that attempt to combine the scale advantages of large firms with the speed and flexibility of smaller firms. It is shown that, contrary to conventional wisdom, large firms have played a central role in the coordination and development of the Taiwanese computer industry; they have also acted as important sources for knowledge creation in small firms.

Issues for Future Research

The great advantage of Taiwan´s computer industry has been the incredible *speed* with which it has been able to respond to changes in markets and technology. Such quick response and flexibility now needs to be supplemented with *industrial deepening*—the development of a domestic supply base for key components and improved product differentiation capabilities. Obviously, this poses a crucial challenge for the Taiwanese approach to knowledge creation management. It also highlights important issues for future research.

Apart from strengthening their domestic R&D capabilities, Taiwanese firms will also need to locate R&D labs as listening posts abroad in the relevant centers of excellence in the US, Japan and Europe. To do this requires a variety of joint ventures and strategic alliances with major international electronics firms, i.e. a transition to *joint*

knowledge creation. Simultaneously, a concerted effort is required to move beyond an exclusive focus on hardware production and to complement this with attempts to strengthen domestic capabilities in software and information services industries.

The most important issue however that requires empirical research is to what degree peculiar features of Taiwanese management practices that were conducive for entering the global production network circuit, have now reached their limits. This raises for instances questions, like: In light of the pervasive impact of the Internet on the organization of the global computer industry, what changes are necessary in firm organization and strategy to sustain knowledge outsourcing through international linkages?

All of this will require time. What matters is that Taiwan has succeeded to developing a critical mass of knowledge and capabilities that will help this small island economy to cope with future challenges. The Taiwanese model in the computer industry provides clear evidence that small enterprises can succeed in global competition, provided they can rely on knowledge outsourcing through inter-organizational and international linkages. But to sustain these early achievements, it is necessary to continuously upgrade firm organization and strategy.

REFERENCES

Acs, Z.J. and D.B. Audretsch, 1992, Innovation and Small Firms, The MIT Press, Cambridge, Mass.

Andersen, E.S., 1996, "The Evolution of Economic Complexity: A Division-of-Coordination-of Labor Approach", in: E. Helmstaedter and M. Perlman (eds.), Behavioral Norms, Technological Progress, and Economic Dynamics. Studies in Schumpeterian Economics, The University of Michigan Press, Ann Arbor

Badaracco, J.L., 1991, The Knowledge Link: How Firms Compete through Strategic Alliances, Harvard Business School Press, Boston

Bell, Martin and Keith Pavitt [1993], "Technological Accumulation and Industrial Growth: Contrasts Between Developed and Developing Countries:, Industrial and Corporate Change, Vol.2, No.2

Borrus, M., D. Ernst and S. Haggard (eds.), 2000, Rivalry or Riches: International Production Networks in Asia, Routledge, London

Bresnahan, Timothy and Franco Malerba, 1997, " Industrial Dynamics and the Evolution of Firms´ and Nations´ Competitive Capabilities in the World Computer Industry", paper presented to the DRUID seminar on Industrial Dynamics and Competition, June, Skagen, Denmark

Callon, S., 1994, "Different Paths: The rise of Taiwan and Singapore in the global personal computer industry", Japan Development Bank Discussion Paper Series #9404, Tokyo

Caves, R.E.,1982, Multinational Enterprise and Economic Analysis, Cambridge University Press, Cambridge

Chandler, A., 1990, Scale and Scope: The Dynamics of Industrial Capitalism, Belknap Press, Cambridge, Mass.

Chen, Tain-Jy et al, 1995, Taiwan´s Small- and Medium-Sized Firms` Direct Investment in Southeast Asia, Chung-Hua Institution for Economic Research, Tapei

Coombs; R. and Stan Metcalfe; 1998, "Distributed Capabilities and the Governance of the Firm", paper presented at DRUID 1998 Summer Conference, Jutlannd, Denmark, June

Dahlman, C., B. Ross-Larson, and L. Westphal [1987], "Managing Technological Development: Lessons from the Newly Industrialising Countries", World Development, Vol. 15/6

Dunning, John, 1993, Multinational Enterprises and the Global Economy, Addison-Wesley

Ernst, Dieter, 1983, The Global Race in Microelectronics, with a foreword by David Noble, MIT, Campus Publishers, Frankfurt and New York

Ernst, D., 1994a, What are the Limits to the Korean Model? The Korean Electronics Industry Under Pressure, A BRIE Research Monograph, The Berkeley Roundtable on the International Economy, University of California at Berkeley, Berkeley , 129 pages

Ernst, D. 1994b , "Network Transactions, Market Structure and Technological Diffusion - Implications for South-South Cooperation", in: L. Mytelka (ed.), South-South Cooperation in a Global Perspective, Development Centre Documents, OECD, Paris

Ernst, D., 1997 a, “Partners in the China Circle? The Asian Production Networks of Japanese Electronics Firms”, in: Barry Naughton (ed.), The China Circle, The Brookings Institution Press, Washington, D.C.

Ernst, D. 1997 b, From Partial to Systemic Globalization. International Production Networks in the Electronics Industry, report prepared for the Sloan Foundation, jointly published as The Data Storage Industry Globalization Project Report 97-02, Graduate School of International Relations and Pacific Studies, University of California at San Diego, and BRIE Working Paper # 98, the Berkeley Roundtable on the International Economy (BRIE), University of California at Berkeley, April 1997. (94 pages).

Ernst, D., 1998a, “Catching-Up, Crisis and Industrial Upgrading. Evolutionary Aspects of Technological Learning in Korea`s Electronics Industry “, in: Asia Pacific Journal of Management (John Wiley), 1998, Volume 15, #2

Ernst, D., 1998b, “High-Tech Competition Puzzles. How Globalization Affects Firm Behavior and Market Structure in the Electronics Industry”, Revue d`Economie Industrielle, No.85

Ernst, D., 2000 a, “Globalization and the Changing Geography of Innovation Systems. A Policy Perspective on Global Production Networks”, special issue of the Journal of the Economics of Innovation and New Technologies , on “Integrating Policy Perspectives in Research on Technology and Economic Growth”, edited by Anthony Bartzokas and Morris Teubal

Ernst, D., 2000b, ”Moving beyond the Commodity Price Trap. How the Crisis Reshapes Upgrading Options for East Asia`s Information Industries”, background study prepared for the World Bank report East Asia: Out of the Crisis, Into the New Millenium, The World Bank, Washington, D.C.

Ernst, D., 2000c, “Carriers of Cross-Border Knowledge Migration: Information Technology and Global Production Networks”, paper prepared for Schumpeter Society Conference, June 28- July1

Ernst, D., 2000d, “The Internationalization of Knowledge Support Functions. Global Production Networks in Information Industries”, in: Research Policy

Ernst, Dieter and David O'Connor,[1989, Technology and Global Competition. The Challenge for Newly Industrialising Economies, OECD Development Centre Studies, Paris

Ernst, D. and O'Connor, D., 1992, Competing in the Electronics Industry. The Experience of Newly Industrialising Economies, Development Centre Studies, OECD, Paris

Ernst, Dieter and Bengt-Åke Lundvall, 1997, “Information Technology in The Learning Economy - Challenges for Developing Countries.” , Danish Research Unit for Industrial Dynamics (DRUID) Working Paper # 97-12, Department of Business Studies, Aalborg University, Denmark.

Ernst, D., L. Mytelka and T. Ganiatsos, 1998, "Export Performance and Technological Capabilities - A Conceptual Framework", chapter I in: Ernst, D. ; T. Ganiatsos and L. Mytelka (eds.), Technological Capabilities and Export Success - Lessons from East Asia, Routledge Press, London etc.

Ernst, Dieter and Paolo Guerrieri, 1998, "International Production Networks and Changing Trade Patterns in East Asia. The Case of the Electronics Industry", Oxford Development Studies, Vol.26, No.2, June

Ernst, D. and J. Ravenhill, 1999, "Globalization, Convergence, and the Transformation of International Production Networks in Electronics in East Asia", Business & Politics (UC Berkeley), Vol I#1

Ferguson, Charles H., 1990, "Computers and the Coming of the U.S. Keiretsu", Harvard Business Review, July-August

Flamm, Kenneth, 1988, Creating the Computer. Government, Industry and High Technology, The Brookings Institution, Washington, D.C.

Freeman, C. and B.A. Lundvall (eds.), 1988, Small Countries Facing the Technological Revolution, Pinter Publishers, London

Gerybadze,A. and G. Reger, 1997, "Globalisation of R&D: Recent Changes in the Management of Innovation in Transnational Corporations", Discussion Paper on International Management and Innovation # 97-01, Center for International management and Innovation, University of Hohenheim

Granstrand, O., L. Håkanson and S. Sjoelander, 1993, "Internationalization of R&D - a survey of some recent research", Research Policy, vol.22

Grossman, G.M. and E. Helpman, 1991, Innovation and Growth in the Global Economy, Cambridge, Mass

Grossman, G.M. and E. Helpman, 1993, "Endogenous Innovation in the Theory of Growth", working paper # 4527, National Bureau of Economic Research (NBER), Cambrige, Mass.

Harrison, B.,1994, Lean and Mean. The Changing Landscape of Corporate Power in the Age of Flexibility, Basic Books, New York

Hobday, M., 1995, Innovation in East Asia: The Challenge to Japan, Edward Elgar, Aldershot

Hymer, S.H., 1960/1976, The International Operations of National Firms: A Study of Direct Investment, MIT Press, Cambridge, Mass.

Kogut, B. and E. Zander [1993], " Knowledge of the Firm and the Evolutionary Theory of the Multinational Corporation", Journal of International Business Studies, Vol.24, No.4

Lall, S. (1990), Building Industrial Competitiveness in Developing Countries, OECD Development Centre Studies, Paris

Lall, S., 1997, "Technological Change and Industrialization in the Asian NIEs: Achievements and Challenges", paper presented at international symposium on "Innovation and Competitiveness in Newly Industrializing Economies", Science & Technology Policy Institute, Seoul, Korea, May 26-27.

Lam, D. K.K. and I. Lee, 1992, "Guerrilla Capaitalism and the Limits of Static Theory: Comparing the Chinese NICs", in: C. Clark and S. Chan, eds., The Evolving Pacific Basin in the Global Political Economy. Domestic and International Linkages, Lynne Rienner Publishers, Boulder & London

Langlois, R.N., 1992, "External Economies and Economic Progress: The Case of the Microcomputer Industry", Business History Review,#66, spring 1992

Langlois, Richard N. and W. Edward Steinmueller, 1997, "The Evolution of Competitive Advantage in the Global Semicondcutor Industry: 1947-1996", paper presented to the DRUID seminar on Industrial Dynamics and Competition, June, Skagen, Denmark

Lee, Ji-Ren and Jen-Shyang Chen, 1998, "Dynamic Synergy Creation with Multiple Business Activities: Toward a Competence-Based Business Model for OEM Suppliers", May, Department of International Business, National Taiwan University, Taipei, Taiwan

Lim, Linda and Pang Eng Fong, 1991, Foreign Direct Investment and Industrialisation´in Malaysia, Singapore, Taiwan and Thailand, OECD Development Centre Study

Liu, C. Y.,1993, "Government´s role in developing a high-tech industry: the case of Taiwan´s semiconductor industry", Technovation, Vol 13, #5

Liu, P.C., Y.C. Liu and H.L.Wu, 1994, "Emergence of New Business Organization and Management in Taiwan", Industry of Free China, Taipei, November

Luethje, B., 1999, Produktionsstrategien, Zulieferernetze und Arbeitsbeziehungen in der EDV-Industrie des Silicon Valley, ("Production Strategies, Supply Networks and Work Relations in the Computer Industry of Silicon valley"), in German, habilitation, department of Social Science, Johann Wolfgang Goethe-Universitaet Frankfurt am Main

Lundvall, B.A., (ed.), 1992, National Systems of Innovation: Towards a Theory of Innovation and Interactive Learning, Pinter Publishers, London

Malerba, F. and L. Orsenigo, 1996, "The Dynamics and Evolution of Industries", Industrial and Corporate Change, Vol. 5, no.1

Maskell, P., 1996, "Learning in the village economy of Denmark. The role of institutions and policy in sustaining competitiveness", DRUID Working Paper # 96-6, Department of Industrial Economics and Strategy, Copenhagen Business School, May

Miner, A. S. and P.S. Haunschild, 1995, "Population Level Learning", Research in Organizational Behavior, Vol.17, pages 115-166.

Ministry of Economic Affairs (MOEA), 1991, Small and Medium Enterprises White Paper, Taipei, Taiwan

Nelson, R. (ed.), 1992, National Innovation Systems, Oxford University Press, London etc

Nelson, R. and H. Pack, 1995, "The Asian growth miracle and modern growth theory", manuscript, School of International and Public Affairs, Columbia University, December

Nelson, R. and S. G. Winter, 1982, An Evolutionary Theory of Economic Change, Bellknap Press, Cambridge:Mass

Pavitt, K., 1998, "Technologies, Products and Organization in the Innovating Firm: What Adam Smith Tell Us and Joseph Schumpeter Doesn't", paper presented at DRUID 1998 Summer Conference, Jutlannd, Denmark, June

Patel,P. and K. Pavitt , 1991, "Large Firms in the Production of the World`s Technology: An Important Case of `Non-Globalisation`", Journal of International Business Studies, 22: 1-21

Nonaka, I. and H. Takeuchi (1995), The Knowledge Creating Company, Oxford University Press, Oxford.

Penrose, Edith, T., 1959/1995, The Theory of the Growth of the Firm, Oxford University Press, Oxford

Richardson, G.B., 1960/1990, Information and Investment, Oxford University Press, Oxford

Richardson, G.B., 1997, "Economic Analysis, Public Policy and the Software Industry", DRUID Working Paper # 97-4, April

Rugman, A.M., 1997, "Canada", chapter 6, in: J.H. Dunning (ed.), Governments, Globalization and International Business, Oxford University Press, London etc

San Gee and Wen-jeng Kuo, 1998, "Export Success and Technological Capability: Textiles and Electronics in Taiwan", chapter II in: Ernst, D. ; T. Ganiatsos and L. Mytelka (eds.), Technological Capabilities and Export Success - Lessons from East Asia, Routledge Press, London etc.

San Gee, 1990, "The status and an evaluation of the electronics industry in Taiwan", OECD Technical Papers,# 29, OECD Development Centre, Paris

San Gee, 1995, Technology Support Institutions and Policy Priorities for Industrial Development in Taiwan, R.O.C. , report prepared for the Ministry of Economic Affairs, Taipei, Taiwan

Saxenian, A., 1994, Regional Advantage. Culture and Competition in Slicon Valley and Route 128, Harvard University Press, Cambridge/Mass

Scitovsky, T.,1986, "Economic development in Taiwan and South Korea, 1965-1981", in: L. Lau (ed.), Models of Development: A Comparative Study of Economic Growth in South Korea and Taiwan, Institute for Contemporary Studies, San Francisco

Shieh, G.S., 1990, Manufacturing "Bosses": Subcontracting Networks under Dependent Capitalism in Taiwan, dissertation, department of sociology, University of California at Berkeley

Spender, J.-C., 1998, "The Geographies of Strategic Competence: Borrowing from Social and Educational Psychology to Sketch an Activity and Knowledge-Based Theory of the Firm", chapter 18 in: Chandler et al (eds), The Dynamic Firm. The Role of Technology, Strategy, Organization, and Regions, Oxford University Press, Oxford etc.

Sturgeon, T. and R. Florida, Final Report to the Alfred P. Sloan Foundation on Globalization of the Automobile Industry, May 26

Teece, D., 1986, "Profiting from technological Innovation", Research Policy, 15/6: 285-306

Teece, D., 1998, "Design Issues for Innovative Firms: Bureaucracy, Incentives and Industrial Structure", in: Chandler et al (eds), The Dynamic Firm. The Role of Technology, Strategy, Organization, and Regions, Oxford University Press, Oxford etc.

von Hippel, E.,1988, The Sources of Innovation, Oxford University Press, New York and Oxford

Wade, R., 1990, Governing the Market: Economic Theory and the Role of Government in East Asian Industrialization, Princeton University Press, Princeton

Walsh, V., 1987, "Technology, Competitiveness and the Special Problems of Small Countries", STI Review, #2, OECD, Paris

Wong Poh Kam, 1991, Technological Development through Subcontracting Linkages, Asia Productivity Organization (APO), Tokyo

Wong Poh Kam, 1995, “Competing in the Global Electronics Industry: A Comparative Analysis of the Strategy of Taiwan and Singapore”, paper presented at the international conference on “The Experience of Industrial Development in Taiwan”, National Central University, Taiwan, May

Wong, Poh Kam, 1999, “National Innovation Systems for Rapid Technological Catch-Up: An analytical framework and a comparative analysis of Korea, Taiwan and Singapore.”, Centre for Management of Innovation & Technopreneurship, National University of Singapore

Zander, U. and B. Kogut, 1995, “Knowledge and the speed of the transfer and imitation of organizational capabilities: An empirical test”, Organizational Science, Vol 6, #1