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Trends in Public and Private Investments in ICT R&D in Taiwan

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PREFACE

R&D activity in the Information and Communication Technologies (ICT) industrial sectors is an important factor in boosting the competitiveness of the European economy. The ICT industry and ICT-enabled innovation in non-ICT industries and services is making an increasingly important contribution to economic growth in advanced economies. The ICT sector was highlighted in the EU Lisbon Objectives, and has retained its prominence in the recently proposed **Europe 2020 Strategy**.

The Information Society Unit at IPTS[1] is carrying out a research project on Prospective Insights on R&D in ICT (PREDICT)[2] and has produced a series of annual reports.[3] PREDICT combines, in a unique way, three complementary perspectives: national statistics (covering both private and public R&D expenditures), company data, and technology-based indicators. PREDICT relies on the latest available official statistics delivered by Member States, Eurostat and the OECD.

The first part of each annual PREDICT report gathers the most recent quantitative information on ICT R&D investments in the EU and worldwide. It presents the data by countries, sub-sectors and companies. The second part of each report is dedicated to a specific thematic analysis. In 2009, the thematic analysis focused on patents data analysis. In 2010, it focuses on internationalisation of ICT R&D.

As an extension of these existing research efforts, IPTS launched a tender for research focused on R&D in ICT sectors in India, China and Taiwan, in order to gain a better understanding of major ICT R&D capabilities in those parts of the world. The 2011 PREDICT report offers a country-level approach to ICT R&D internationalisation by analysing the ICT industry in China and India, the two largest emerging economies. It then provides a first synthesis of the research.[4]

This research exercise led to three further reports on China, India and Taiwan, each one including a dataset and a technical annex. These reports have been written by national experts under the coordination of the International Centre for Economic Growth (ICEG, Hungary).

Tribute to Pál Gáspár

Pál Gáspár was the founding Director of the International Centre for Economic Growth (ICEG European Centre). He and his team of researchers have collaborated with IPTS on numerous successful research projects and he was a project leader for the overall study of which this report is a part.

We would like to acknowledge his invaluable contribution to this project. His professionalism will be greatly missed. He was an enlightened economist, a fascinating Professor and a creative Director. For us, however, his values, attitude to life, and openness made him, first and foremost, a friend.

Marc Bogdanowicz
Information Society Unit, IPTS

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1 IPTS (the Institute for Prospective Technological Studies) is one of the 7 research institutes of the European Commission's Joint Research Centre.

2 PREDICT is co-financed by JRC-IPTS and the Information Society & Media Directorate General of the European Commission.

3 Available on our website under the link http://is.jrc.es/pages/ISG/PREDICT.html

4 Also based on these country reports and further research, IPTS is preparing a report on ICT in BRIC countries. For more, see under Simon J-P (2011) (forthcoming).

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3G: Third Generation Mobile Communications
4G: Fourth Generation Mobile Communications
CIER: Chung-Hua Institution for Economic Research
DRAM: Dynamic Random Access Memory
ECFA: Economic Cooperation Framework Agreement (between Taiwan and China)
EDA: Electronic Design Aid
GIN: Global Innovation Network
GPN: Global Production Network
IC: Integrated Circuit
ICT: Information and Communications Technologies
IDM: Integrated Device Manufacturers
III: Institute for Information Industry
ITRI: Industrial Technology Research Institute
PC: Personal Computer
LCD: Liquid Crystal Display
LCM: LCD Modules
LED: Light Emitting Diode
MNCs: Multinational Corporations
MOEA: Ministry of Economic Affairs (Taiwan)
NIS: National Innovation System
NB Computer: Notebook Computer
OEM: Original Equipment Manufacturing
ODM: Original Design Manufacturing
OS: Operating System
R&D: Research and Development
SOC: System on a Chip
TD-LTE: Time-Division Long Term Evolution (a 4G standard)
TD-SCDMA: Time-Division Synchronous Code Division Multiple Access (a 3G standard)
TSMC: Taiwan Semiconductor Manufacturing Corporation

EXECUTIVE SUMMARY

Ever since the 1980s, the ICT industry has been the paramount engine of economic growth in Taiwan, with many Taiwanese-made ICT hardware products enjoying a significant global market share. Both FDI and technology transfer from the advanced countries, particularly the USA and Japan triggered local firms' entry into different subsectors over time, from the computing/communications manufacturing, Integrated Circuits (IC) and more recently to Liquid Crystal Display (LCD) subsectors. However, local firms have managed to establish strong technological and innovation capabilities through internal R&D, technology transfer from local research institutes, and the establishment of science parks (first the Hsinchu Science Park, and later several others). Behind this development are the well-regarded production and design capabilities of the Taiwanese ICT producers, which in turn have made Taiwan a major source of contract work for internationally prominent ICT firms.

Taiwan is highly specialised in the ICT sector, in terms of manufacturing GDP, exports, and more importantly R&D expenditures. Taiwan's manufacturing R&D is highly concentrated in the ICT sector, accounting for 69.85% of Taiwan's manufacturing R&D. In addition, offshore production of Taiwan-based computing/communications firms now far outweighs their domestic production. The role played by Taiwan's ICT industry in the global production network (GPN) has shifted from being a key producer and exporter of end products to that of an important manufacturer of components and parts (intermediate goods). This development cannot be reduced to the argument that Taiwan-based ICT end product producers have lost the edge to their international competitors: instead it should be interpreted within the context of the GPN.

Along with the trend towards the formation of a GPN and more recently a global innovation network (GIN), major brand marketers' adoption of outsourcing and order-based production has greatly rationalised their global supply chain, and hence altered their contractual relationships with their Taiwanese counterparts. As a result, Taiwan's ICT firms have participated in cross-border supply-chain management, logistics operations, and after-sales services, by forming a fast-response global production and logistics network. In addition, China has become an increasingly important offshore production site for Taiwan-based PC and notebook computer firms, which has fuelled China's growing significance in the assembly and manufacturing of ICT products. There are even signs that China is playing a growing role in R&D. However, for most ICT firms, particularly the IC and LCD manufacturers, their R&D bases remain largely located in Taiwan. This together with the IC design industry makes Taiwan an innovation hub for the global ICT production network.

Taiwan's ICT industry as a whole has shifted its focus from foreign technology to indigenous innovation. Taiwan's R&D intensity increased to 2.62% in 2007, with about 67% of national R&D expenditure being attributed to the ICT industry. In terms of US patenting, Taiwan ranked fourth for nine years in a row (1999-2007). In sharp contrast, Taiwan has faced a huge and increasing deficit in technological trade. In other words, Taiwan's achievement in international patenting is not proportional to its trade balances in technology, a phenomenon called the "innovation paradox". This paradox can be attributed to characteristic features of Taiwan's National Innovation System (NIS) and the ICT sector.

Apart from FDI in production, some of the MNCs in Taiwan have also invested in R&D. In fact, R&D intensity for foreign-owned subsidiaries in Taiwan's manufacturing sector increased from 1.52% in 2002 to 1.94% in 2003, indicating that Taiwan's involvement has

significantly improved in terms of MNCs' regional or global innovation networks. In addition, the government has orchestrated a plan to encourage MNCs to establish R&D centres on the island, which since its implementation in 2002 has met with some success. In Taiwan there are so far some 42 R&D centres, established by 30 different MNCs. These R&D centres are related mainly to the current strength of Taiwan's industrial development, of which the lion's share (67%) results from the broadly defined ICT area. These centres show a strong disposition to collaborate with local firms.

China has become the major target for Taiwanese ICT firms' offshore R&D in quantitative, though not necessarily qualitative terms. Five types of R&D portfolio can be identified. In addition, both India and China have become high-profile host countries for the offshore R&D facilities of multinational corporations (MNCs). Taken together, new patterns and flavours have emerged from the current trend towards R&D globalisation in Asia, including R&D offshoring, technology sourcing and offshore collaboration. It follows that certain rules of the game for R&D and innovation may have begun to change, at least in relative terms.

On the other hand, the Taiwanese ICT players can still be regarded as an important catalyst in the introduction of brand new or further generations of ICT products to the global market. Therefore, it can be argued that from the perspective of the ICT industry, Taiwan's NIS is closely linked with the GIN led by the brand marketers.

Without denying its significance to the GIN, there are concerns that Taiwanese ICT industry, particularly the computing/communications subsector, is subject to bottlenecks. To overcome these bottlenecks, the government has formulated policies to facilitate the transformation of Taiwan's ICT industry, for example towards the "servitization of manufacturing" and diversification. Indeed, it can be observed that the profiles of Taiwanese ICT firms have started to move away from their previous stereotypes.

Additionally, the government's new policy as regards China includes a set of initiatives to support the national ICT industry. Taiwan has to come to terms with the rise of China by realigning its industrial science and technology development and the relevant policy addressing the cross-strait issues. For example, new initiatives such as cross-strait cooperation in industrial standards, the Building Bridges Project, Economic Cooperation Framework Agreement (ECFA) and the deregulation of Chinese investment to Taiwan have been launched mainly from the Taiwan side and have met with some positive responses from China. For cross-strait cooperation in industrial standards, both sides have reached agreements to work together on the fields of TD-SCDMA, LCD, LED and solar cells.

As far as Taiwan is concerned, cross-strait cooperation in industrial standards is meant to be a way of coming to terms with the rise of China and promoting cross-strait economic relationships beyond the current practice by Taiwan-based firms of relocating their industrial value chain to China. If it is successful, some Taiwanese ICT firms may be able to get involved in the formation of Chinese industrial standards and/or dominant architecture design at the early stage. In addition, new initiatives such as the ECFA and the Building Bridges Project are not meant for Taiwan and China only. Instead, these new initiatives serve to link up the "broken chain" between China and Taiwan in the global context. They will mean that firms from the other countries need not be forced to make a trade-off between China and Taiwan, if they want to explore the economic potential in the Greater China Area.

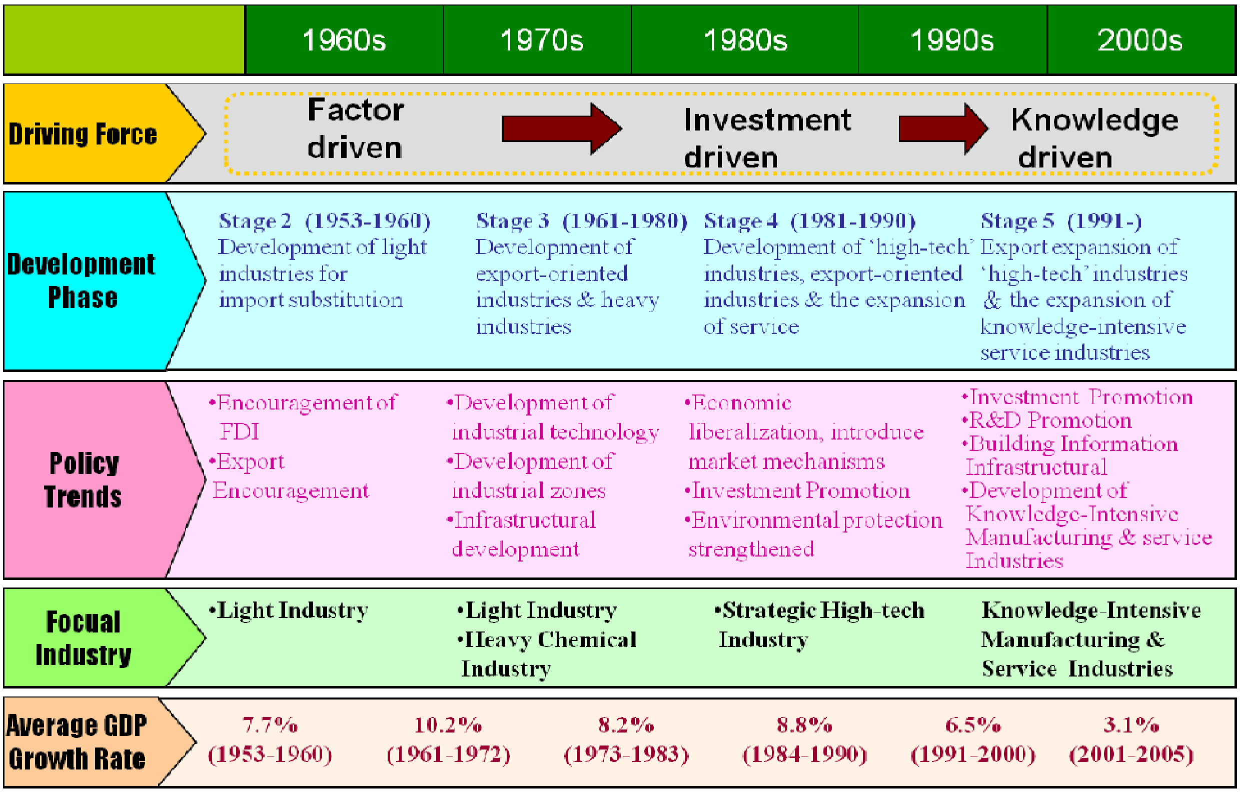
INTRODUCTION

1. Characteristics of Taiwan's Economy

Taiwan used to be well-known as one of the Asian Newly industrialising Countries (NICs) in the late 20th century, with its average annual economic growth rates being as high as 8.2% in the 1980s and 6.5% in the 1990s. On the one hand, in terms of GDP structure, Taiwan's manufacturing sector declined from an all-time peak of 39.4% of GDP in 1986 to a low of 25.0% in 2008. The service sector, by contrast, has followed a constantly rising trend and now accounts for more than 70% of Taiwan's GDP (73.3% in 2008). On the other hand, in terms of annual growth rate, the manufacturing sector still plays a crucial role; and exports have been a major source of Taiwan's economic growth.

Taiwan's economic achievement had much to do with its export-oriented industrialisation strategy. Underlying this was a process of profound transformation of Taiwan's economic structure. Its economic take-off started with the labour-intensive light industries and then the heavy and chemical industries before the 1980s. Taiwan's transition towards the high tech industries began to gather momentum afterwards, giving rise to the fast development of such strategic industries as the ICT hardware, semiconductor and opto-electronic sectors. Right now Taiwan is aiming at marching towards a knowledge-based economy, which may involve new strategic sectors, such as the wireless product & service, healthcare, and digital entertainment industries (Chen and Liu, 2003; Chen, 2004; see Graph 1).

Graph 1: An Overview of Taiwan's Economic Transition

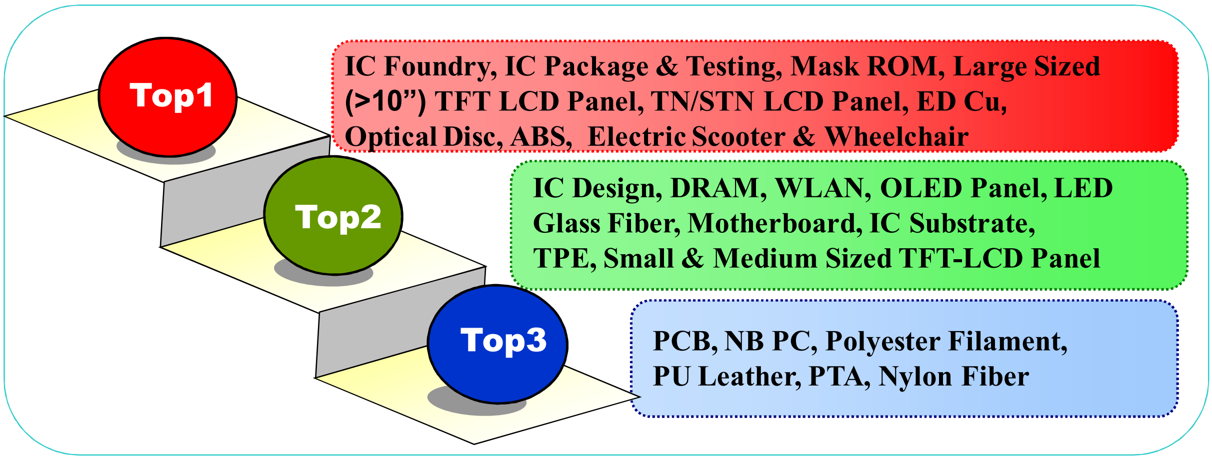


Source: This study.

Ever since the 1980s, the ICT industry has increasingly become the paramount engine of economic growth in Taiwan. On the worldwide scale, Taiwan currently ranks as the fourth largest producer of information hardware, the fourth in the case of Integrated Circuit (IC), and the third in the opto-electronics area. With particular regard to the ICT hardware industry, a number of Taiwanese-made products have enjoyed a significant global market share, to name just a few, including IC foundry, IC package & testing, Liquid Crystal Display (LCD) Panel, Light Emitting Diode (LED) (see Graph 2 for details). What underlie this are the well-regarded production and design capabilities of the Taiwanese ICT producers, which in turn have made Taiwan a major source of contract work for international prominent ICT companies.

There are grounds for suggesting that Taiwan is highly specialised in the ICT sector, in terms of manufacturing GDP (value added), exports, and more importantly R&D expenditures. To unveil the above-mentioned phenomenon, we follow the definition of OECD to classify the manufacturing sectors into four groups; including high technology, medium-high technology, medium-low technology, and low technology sectors. As shown in Graph 3, the high technology sector as a whole accounted for 32.14% of manufacturing GDP in 2006, compared to 24.43% for the medium-high technology sector and 29.45% for the medium low technology sector. More importantly, the lion's share of the high technology sector (31.36% of the manufacturing GDP) is associated with the ICT sector. The high technology industry, the ICT sector in particular, plays a more significant role in Taiwan's manufacturing exports. Out of 39.44% of manufacturing exports by the high technology industry, 39.14% can be attributed to the ICT sector. Even more significant is a high concentration of Taiwan's manufacturing business R&D in the ICT sector. In the high technology sector, the ICT sector accounted for 69.85% of Taiwan's manufacturing business R&D, compared to 1.12% for the non-ICT high technology sector, an issue to be discussed below.

Graph 2: Taiwan's World Leading Products (2007)



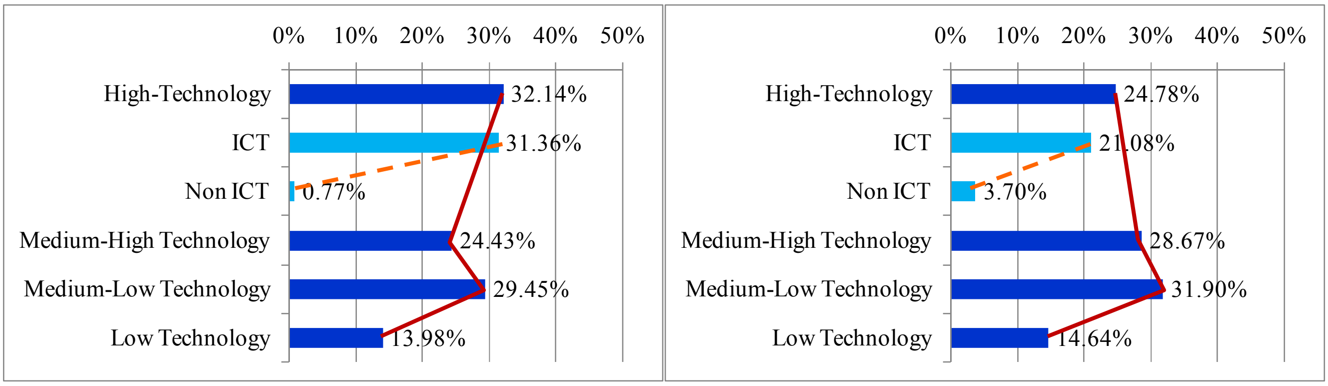
Note: Including both domestic and offshore production.
Source: Compiled by Market Intelligent Center (MIC), Institute for Information Industry (III).

As compared to South Korea, though both countries are known for their high technology industries, South Korean has a relatively strengths in medium high technology sectors, such as the automotive, consumer electronics, shipping industries. In addition, Taiwan's industrial R&D is overwhelming concentrated in the high technology industries, the ICT sector in particular, with this sector alone accounting for more than 70% of Taiwan's R&D performed by the business sector, as compared to 50.82% in South Korea (see Section 4.1 for detailed discussions on Taiwan's BERD in the ICT sector).

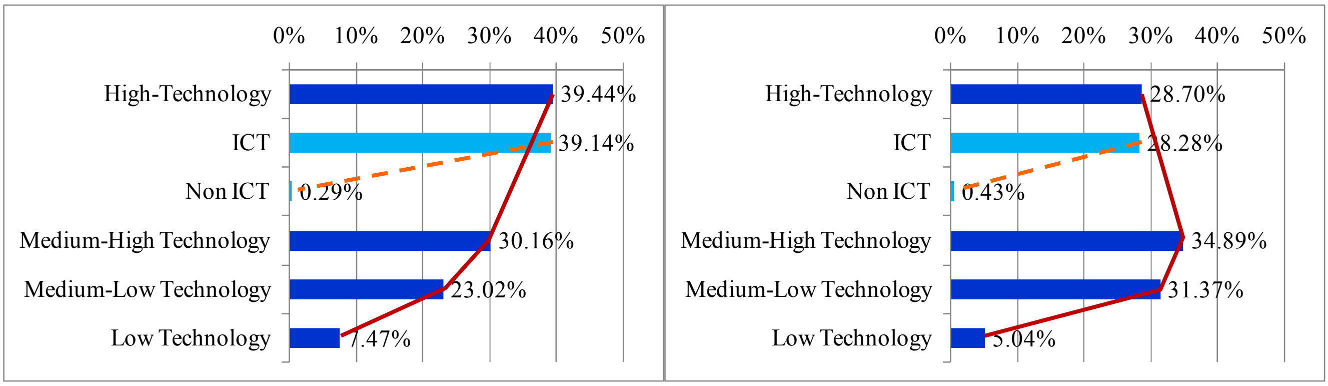
Graph 3: Structural Characteristics of Manufacturing: Taiwan vs. South Korea (2006)

(1) Share of Manufacturing GDP (2006)

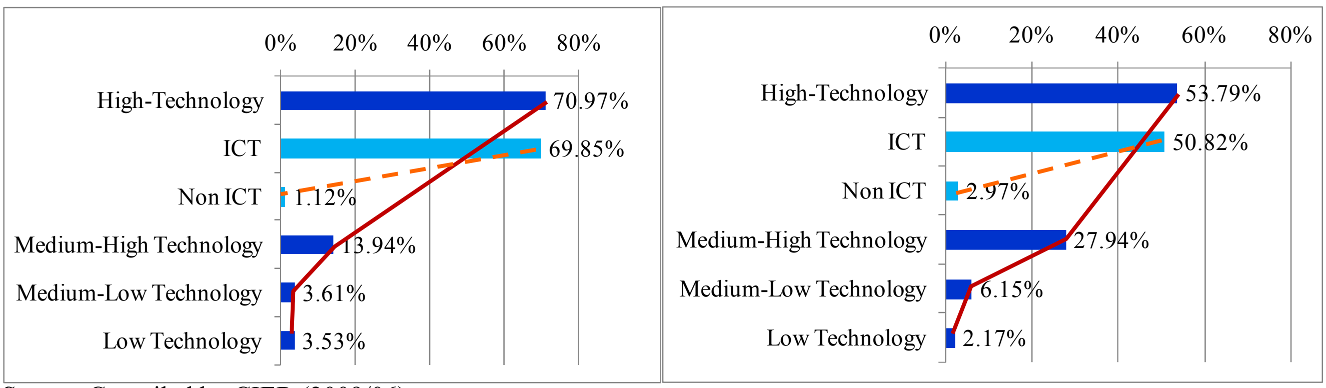
Taiwan **South Korea**



(2) Share of Goods Exports (2006)



(3) Share of Manufacturing R&D (2006)



Source: Compiled by CIER (2009/06).

2. The Rise and Characteristics of Taiwan's ICT Industry

In the 1980s when the ICT industry, the PC subsector in particular, was dominated by vertically-integrated firms in the advanced countries, such as the US and Japan, their outward investment to Taiwan triggered its entry into the value chain at mass production level. Later onwards, the local firms, Acer and Tatung for example, were able to take up the vacuum caused by the withdrawal of the foreign firms during the mid-1980s due to rising production costs at that time, which then laid the foundation for the formation of the local industrial clusters, stretching from Keelung to Hsinchu in the Northern part of Taiwan. Due credit should be given to the public sector for the government's efforts in mobilising such government-sponsored research institutes as the Industrial Technology Research Institute (ITRI) and the Institute for Information Industry (III) for technology upgrading and establishing the Hsinchu Science Park, which has since then developed into the centre of gravity for the local ICT industry.

In addition, the development of Taiwan's IC industry has benefited a lot from technology transfer and international knowledge networking. Technology transfer from RCA (a US electronic firm) to the ITRI initially triggered the emergence of the local IC industry, which was then fuelled by the fast development of the local PC industry in the late 1980s, because of the industrial linkages between these two sectors. In particular, Taiwan Semiconductor Manufacturing Corporation (TSMC), a successful spin-off from the ITRI, pioneered the business model of "dedicated foundry manufacturing service", simply carrying out contract fabrication work for global customers ranging from start-up ventures, well-established IC design houses to world-leading Integrated Device Manufacturers (IDMs) (Chen, 2002). As a result, fabless[5] IC design houses, as well as specialised IC packaging and testing firms, proliferated in Taiwan because access to external fabrication capacity lowered the barriers to entry into the IC design market.[6] On top of that, the geographical concentration of IC and computer-related firms in the Hsinchu Science Park generated agglomeration effects that allowed these firms to exploit the benefits of proximity and outsourcing. Therefore, even though they specialise in one segment of the value chain, IC firms in Taiwan are networked by social and business connections.

It is also evident that Taiwan's IC industry is organised as an industrial network system with a strong connection to Silicon Valley, the centre of the global IC market and of global IC technology. Underlying this exchange were overseas Chinese and Chinese expatriates, who had played an important role in establishing the trans-Pacific social and business networks that had proved crucial in connecting Taiwan's production system with advanced market knowledge and technology. Apart from the ethnic social network, the similarity in industrial structure made networking between Silicon Valley and the Hsinchu Science Park, much easier and more intensive (Saxenian, 1997).

The development of Taiwan's LCD (Liquid Crystal Display) industry came later than did the IC sector, but followed the same pattern, except for the fact that technology transfer came from Japan. To quite an extent, the growing significance of Taiwan-based firms in the production of LCD monitors and notebook computers triggered local firms' entry into the LCD industry in the early 1990s. The government took advantage of this trend by promoting the so-called "Two-Trillion Industries", namely the IC and LCD sectors, from the second half

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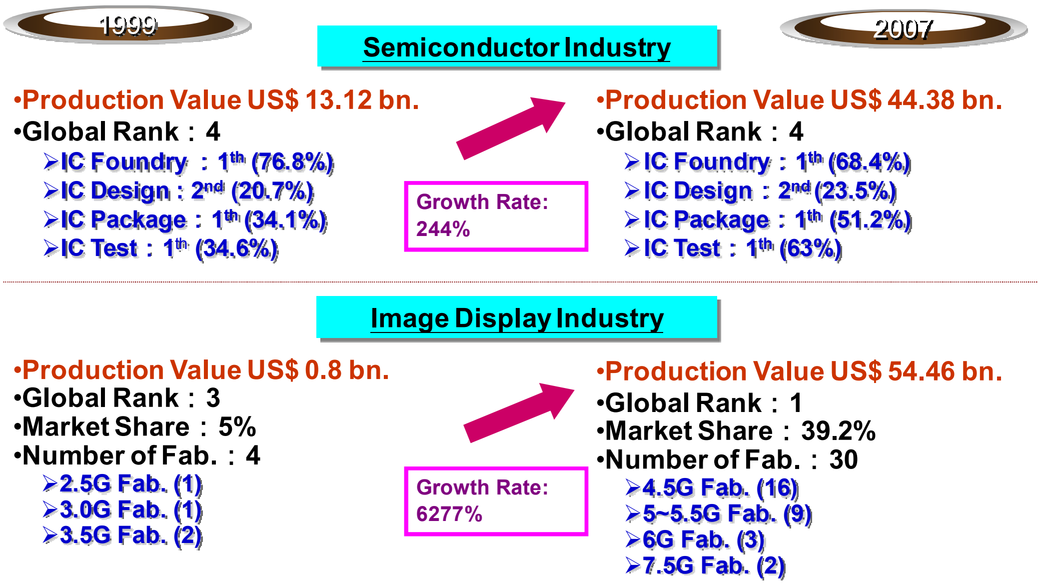
5 A company specialising in the design and sale, but not the fabrication of products.

6 Before TSMC, ICs were designed and manufactured (fabricated) by IDMs in-house. Instead, TSMC provides dedicated foundry manufacturing services to specialised IC design houses and even IDMs.

of the 1990s onwards (See Graph 4). In addition to R&D initiatives and the tax credit scheme, a few other science parks have been established to accommodate a growing number of industrial players in these high-tech industries. Some of them have become so well-established as to become emerging new industrial clusters in Taiwan. Prominent cases at issue include Southern Taiwan Science Park, Central Taiwan Science Park, and Nankang Software Park. In particular, both of Southern Taiwan Science Park and Central Taiwan Science Park, though initially planned for industrial diversification beyond the broadly-defined ICT sector, have developed into two new clusters for the IC and LCD sectors mainly because of the constituent firms' relocation and/or expansion from the Hsinchu Science Park.

Graph 4: The Development of "Two-Trillion Industries" in Taiwan



Source: Complied by MIC, III.

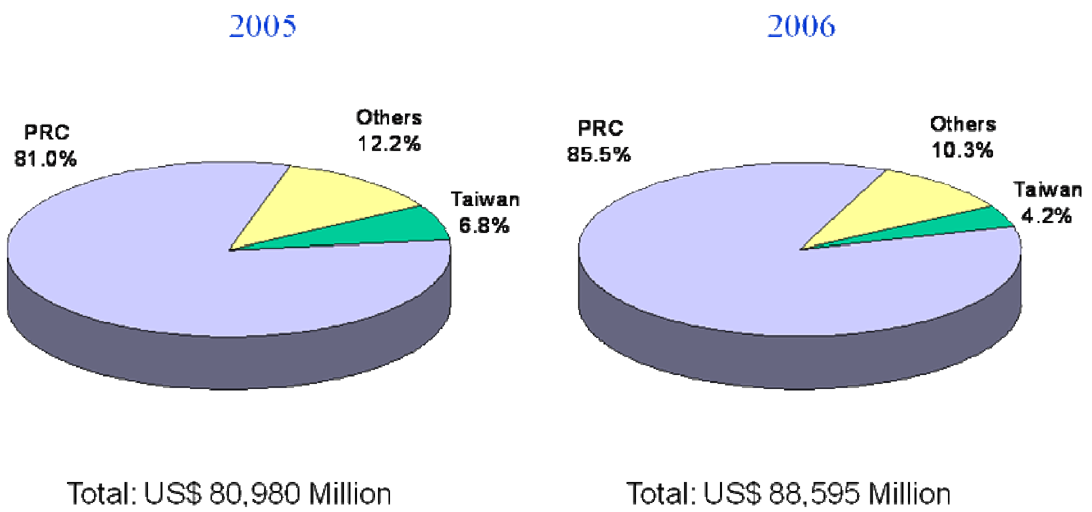
3. Global Production Networks and Taiwan's ICT Industry

However, it should be noted that the development of Taiwan's ICT industry as a whole has gone beyond the paradigm of local clustering, thanks to the formation of the global production network (GPN; Angel and Engstrom, 1995; Ernst, 2006; Chen, 2002; Chen and Liu, 2003). Particularly, outsourcing and offshoring, not only in the manual but also knowledge work, have become widely adopted practices in quite a number of industries as a means of enabling brand marketers to remain cost-competitive, which arguably would lead to further disintegration of innovation capabilities on the global scale.

As a result, the 1990s witnessed the emergence of such countries as Taiwan and Korea as the major players in subcontract work for ICT brand marketers in the advanced countries partly because of the rising popularity of outsourcing. It follows that Original Equipment Manufacturing (OEM), which used to be the major business of the ICT firms in Taiwan, has gradually given way to Original Design Manufacturing (ODM) and, to a less degree, to production under brand names, thus facilitating their involvement in the design value chain at the mass production level. Meanwhile, China's "open door" policy and the outreach of Taiwan's ICT firms fuelled China's growing significance in the assembly and manufacturing of ICT products. Ever since the turn of the new millennium, the evolution has gone further to witness the involvement in R&D by the ICT firms in both Taiwan and South Korea, even China, especially in terms of component technologies, giving rise to the so-called global innovation network (GIN) (Chen, 2004; Ernst, 2006).

An important milestone in the development of Taiwan's PC industry in this regard was the outreach achieved by local firms starting from the late 1980s. Their outward investment was initially directed towards Southeast Asia, but later towards China and elsewhere in the world. The offshore production of Taiwan-based PC firms has nowadays much outweighed their domestic production (see Graph 5 for details).

Graph 5: Production Locations of the Taiwanese ICT Hardware Firms, 2005-2006



Note: ICs and LCD panels are not included because they are mostly manufactured in Taiwan.
Source: MIC/III, January 2007

With the PC industry's drive to reduce production costs, lead-time to market, and inventory costs came a profound change in the manufacturing system and inter-firm competition in the industry. It became commonplace for components to be sourced from a global network of suppliers and for final assembly to be done within the end-market (Angel and Engstrom, 1995; Borrus and Borrus, 1997). Specifically, major brand marketers moved to adopt outsourcing and order-based production, which greatly rationalised their global supply chain, and hence altered their contractual relationships with their Taiwanese counterparts.

Such contractual arrangements with global leaders in the PC industry have prompted Taiwan's ICT firms to upgrade their position within the global production system. Taiwan's firms began to shoulder the essential functions of co-ordinating the global supply chain for their OEM customers. A number of brand marketers outsourced every element of the value chain except marketing to Taiwan's subcontractors, and completely handed over its inventory costs to these subcontractors, who were also required to produce and deliver subsystem products on tight schedules and in tune with the vagaries of market demand. The Taiwan's firms had to ensure that everything was synchronised up and down the supply chain. In order to do this they had to participate in cross-border supply-chain management, logistics operations, and after-sales services and to co-ordinate all of these they had to form a fast-response global production and logistics network (Chen and Liu, 2003).

As part of this process, in recent years, the electronics and electrical appliances industry has accounted for approximately 40% of Taiwan's annual outward investment to China. More importantly, China has become an increasingly important offshore production site for Taiwan-based PC and notebook computer firms, with having significantly outweighed the latter's domestic production since 2002. The outreach of Taiwan's ICT firms fuelled China's growing significance in the assembly and manufacturing of ICT products. Ever since the turn of the new millennium, China's coverage of the value chain at the mass production level has become more comprehensive. There are even signs that China is increasingly playing a growing role in R&D, a point we shall return later in Section 3.2.2.

On balance, GPNs in ICT industry have come to the fore. Characteristic features of the GPNs include cross-border modularised production and speedy patchy production, instead of production under one-roof and mass production as before. Therefore, from the standpoint of Taiwan's ICT producers, the triangular linkages involving Taiwan (Hsinchu), China (the Yangtze River Delta), and the USA (Silicon Valley) may mean much more to their prosperity than does the local industrial cluster in Taiwan.

To facilitate the innovation network between Taiwan's ICT firms and their network flagship counterparts, the Taiwanese government has since 2001 sponsored a series of Benchmark Project of e-Business in the ICT industry, also known as Plan A, B, C, D, E and G. In Plan A, 44 major domestic system suppliers worked with three international ICT companies, IBM, Compaq and HP, to construct the electronic supply chain from designing to purchasing. Plan B was for 15 local leading system manufacturers and the upstream components suppliers to establish the electronic supply chain from purchasing to manufacturing. Building on the success of plans A and B, the government has expanded e-business application in the information and semiconductor industries to promote plans C, D, E, and G for cash flows, delivery flows, engineering and green manufacturing respectively. The scope of these plans includes promoting electronic payments, e-financing and capital management for cash flows, delivery tracing management and transportation planning for delivery flows, and simultaneous R&D, design changes and information sharing for collaboration. As a result, the Taiwanese ICT firms together with their global partners are involved in not only inter-organisational coordination of the supply chain but also cooperation in product definition, design, and R&D. In this way, inter-organisational and cross-border production networks in the "bricks and mortar" world are transformed into virtual supply networks and collaborative communities (Chen, 2002). In addition, a programme was launched in 2002 to encourage MNCs to establish R&D centres in the island, to be discussed in Chapter 3. More recent policy focus is geared even to the development of Clouding Computing, Internet of Things, and the Servitisation of Manufacturing.

CHAPTER 1. DESCRIPTIVE PRESENTATION OF THE ICT SECTOR

1.1 An Overview of Taiwan's ICT Industry

The ICT industry has been considered as a sector of landmark underlying the success of Taiwan's export-led industrialisation and cluster-based development. Taiwan has been widely regarded as one of the major players in the ICT industry and quite a number of Taiwanese-made products, though not necessarily made in Taiwan, within the ICT subsectors, such as motherboards, scanners, monitors, notebook computers, IC, and LCD panels enjoy significant global market shares, as shown earlier. It should be noted that Taiwan's industrial clusters of the ICT sector do not arise within a historical vacuum, nor are they isolated from the rest of the world; this is not to deny the importance of local milieu in the formation of industrial clusters, but rather, a recognition of the role of international linkages, through trade, technology transfer and knowledge networking, in the development of the local industrial clusters.

Taiwan's ICT firms have initially entered a particular product market as "fast followers" during the growth stage, with a key success factor being the capacity to combine low-cost production in Taiwan with a rapid response to changes in markets and technology. Nowadays, however, it is far too simplistic to state that Taiwan's success in the ICT industry is attributable to manufacturing muscle alone; so too is the thesis on Taiwan's local industrial clustering.

On the one hand, there are grounds to suggest that Taiwan's ICT sector has moved from foreign technology to indigenous innovation. To quite an extent, Taiwan's ICT firms tend to pursue technological innovation on the pathway led by the architectural design created by leading brand marketers and/or industrial standard setters. As the network flagships, in Ernst's (2006) terms have become hollowing-out, part of their innovation offshoring tends to take the form of farming out to layers of specialised suppliers. On the other hand, Taiwan's ICT industry has gone global and has become an essential part of the global production and innovation network (Angel, and Engstrom, 1995; Ernst, 2006; Chen, 2002; Chen and Liu, 2003). The latter, in particular, has much to do with the trend towards globalisation and the rapid emergence of China.

The GDP share of Taiwan's ICT manufacturing is indeed relatively high, compared to many other countries, being as high as 7.064% in 2006, set against 23.0% for the manufacturing sector as a whole. Out of this percentage, 5.133% can be attributed to the segment of 3210 (Manufacture of electronic valves and tubes and other electronic components), which is associated mainly with the semiconductor and LCD industries (see Table 1). Both of these two sectors are also known in Taiwan as "Two Trillion Industries" and have been actively promoted by the government. In fact, according to results of the Industry, Commerce and Service Sector Census[7] (ICSS Census) for 2006, these two sectors' combined revenues amounted to NT$2,310 billion (about US$71.01billion) in 2006, registering a substantial increase from NT$897 billion (about US$26.54billion) in 2001, accounting for 67.79% of the incremental revenues over the period 2001-2006 for the so-called "non-traditional sectors" (see Table 3, below). This has something to do with the Taiwan-based ICT firms' offshore

[7] This census is conducted every five years by the Directorate General of Budget, Accounting and Statistics (DGBAS).

relocation of the downstream manufacturing operations in the PC, notebook computer, handset and other ICT devices and components subsectors. As a matter of fact, even such brand new products as Wii, Xbox, iPhone nowadays are mostly made/assembled in China and/or Southeast Asia, because mainly of manufacturing offshoring by the Taiwan-based ICT OEM/ODM firms.

The ICT sector has also played an important role in Taiwan's exports. Taiwan's trade balances generated by the six categories of ICT goods increased from NT$348.24 billion (about US$12.15 billion) in 1997 to NT$902.16 billion (about US$27.73 billion) in 2006 (see Table 2), which was about 1.34 times of the total trade balances (NT$674.98 billion, or US$20.75 billion) for that year. Referring to the breakdown of the ICT goods, there has been a substantial shift in the export structure of Taiwan's ICT goods. Around the turn of the new millennium, "computer and related equipment" used to be the major category of Taiwan's exports of ICT goods, followed by the item of "electronic components". Afterwards, the latter has gained growing significance in terms of its export values and ratio to ICT exports, with its export values increasing from NT$862.80 billion (about US$27.63 billion) in 2000 to NT$1,541.02 billion (about US$47.37 billion) in 2006, and accounting for 61.97% of Taiwan's ICT exports in 2006. For the same year, 46.63% of the trade balances generated by all categories of ICT goods was accounted for by the item of "electronic components", which were related mainly to the Two Trillion (IC and LCD) sectors. In other words, Taiwan's ICT exports nowadays is highly concentrated in the ICT intermediate goods, rather than the ICT end products, which coincides with the fact that around 70% of Taiwan's exports is related to intermediate goods.

Graph 6 illustrates for Taiwan's ICT sector its profound change in export structure in a different way. In Taiwan, the official data for ICT goods exports can be categorised into five sub-sectors, namely telecommunications equipment, computer and related equipment, electronic components, audio and video equipment, and other ICT goods. In 1997, the computer and related equipment sector accounted for 48.70% of Taiwan's ICT goods exports, and reaching its all-time peak of 51.60% in 1998, while the electronic components sector accounted only for 37.12%. Since then, the computer and related equipment sector's export share has declined over time, down to the level of 15.46% in 2006. On the other hand, the electronic components sector has gained substantially its export share, reaching 61.97% in 2006, which has much to do with the burgeoning development of the IC and LCD industries in Taiwan. In other words, in terms of domestic production, the role played by Taiwan's ICT industry in the GPN has shifted from a key producer of end products to that of important components and parts (intermediate goods).

In addition, the so-called "electronic products" and "information and communications (end) products" accounted for 22.99% and 20.63% respectively of the volume of total export orders received by Taiwan in 2006, with a combined total of 43.62%. Interestingly, in terms of their share of the volume of Taiwan's actual exports, it was 28.04% for "electronic products", but only 4.41% for "information and communications products". In other words, for "information and communications products", their volume of actual exports is not proportional to that of export orders. In fact, for this category of products, there has been an increasing divergence between the volume of export orders received and that of their actual exports (see Graph 7), indicating a significant ratio of offshore production by the Taiwan-based OEM/ODM firms. This development cannot be reduced to the argument that the Taiwan-based ICT end product producers have lost edges to their international competitors, instead should be interpreted within the context of the GPN, an issue to be discussed in the next section.

Table 1: Value Added of Taiwan's ICT Subsectors and their GDP Shares

Unit: In national currency, Millions of NT$, at current prices

Year	2001		2002		2003		2004		2005		2006	
NACE categories relating to ICT	national currency	% of GDP	national currency	% of GDP	national currency	% of GDP	national currency	% of GDP	national currency	% of GDP	national currency	% of GDP
ICT Manufacturing	596,676	6.050	726,583	7.059	773,284	7.351	797,564	7.208	793,511	6.927	839,885	7.064
3000 Manufacture of office, accounting and computing machinery	161,113	1.634	181,493	1.763	171,439	1.630	125,224	1.132	120,757	1.054	124,003	1.043
3130 Manufacture of insulated wire and cable	15,266	0.155	16,462	0.160	16,433	0.156	17,352	0.157	19,088	0.167	22,071	0.186
3210 Manufacture of electronic valves and tubes and other electronic components	354,348	3.593	453,279	4.404	501,573	4.768	580,351	5.245	574,501	5.015	610,253	5.133
3220 Manufacture of television and radio transmitters and apparatus for line telephony and line telegraphy 3230 Manufacture of television and radio receivers, sound or video recording or reproducing apparatus, and associated goods	60,265	0.611	69,390	0.674	76,095	0.723	65,800	0.595	66,570	0.581	68,363	0.575
3312 Manufacture of instruments and appliances for measuring, checking, testing, navigating and other purposes except industrial process control equipment 3313 Manufacture of industrial process control equipment	5,684	0.058	5,959	0.058	7,745	0.074	8,837	0.080	12,596	0.110	15,195	0.128

Source: The Directorate General of Budget, Accounting and Statistics (DGBAS) of Executive Yuan, Statistical Abstract of National Income, R.O.C., compiled by CIER.

Table 2: Export Values of Taiwan's ICT Subsectors

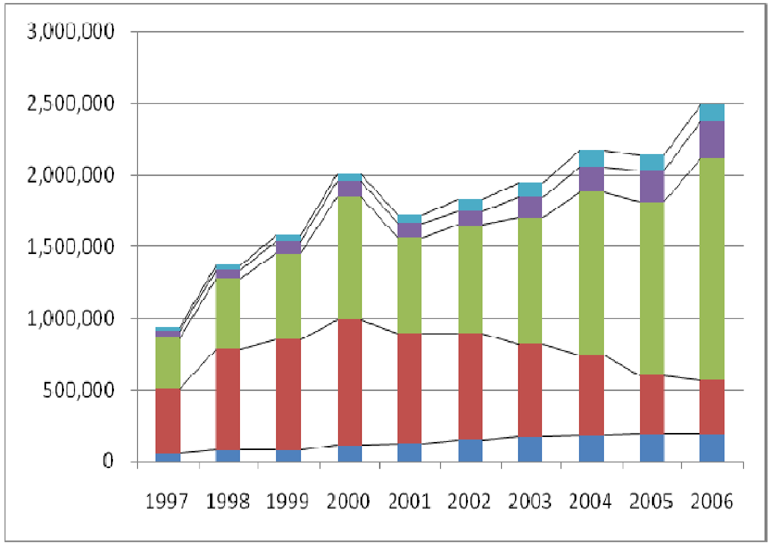
Unit: In national currency, millions of NT$, at current prices

Year	1997			1998			1999			2000			2001		
The categories relating to ICT Goods	exports	imports	trade balance	exports	imports	trade balance	exports	imports	trade balance	exports	imports	trade balance	exports	imports	trade balance
Telecommunications equipment	53,125	31,981	21,143	75,873	63,044	12,829	78,479	77,516	962	112,008	109,342	2,666	123,488	92,863	30,625
Computer and related equipment	456,454	85,093	371,360	706,937	168,846	538,091	770,163	272,477	497,685	873,497	311,009	562,488	766,636	222,792	543,844
Electronic components	347,914	374,221	-26,306	492,033	562,702	-70,668	600,627	594,703	5,924	862,799	795,824	66,975	671,632	664,379	7,253
Audio and video equipment	53,912	21,369	32,543	61,447	24,596	36,851	89,881	24,227	65,654	106,504	26,878	79,625	101,807	24,199	77,608
Other ICT goods	25,951	76,450	-50,499	33,857	78,491	-44,635	36,561	90,544	-53,984	50,797	154,852	-104,055	58,075	103,561	-45,486
Total ICT Goods	**937,356**	**589,114**	**348,242**	**1,370,146**	**897,679**	**472,467**	**1,575,710**	**1,059,468**	**516,242**	**2,005,604**	**1,397,905**	**607,699**	**1,721,639**	**1,107,794**	**613,844**

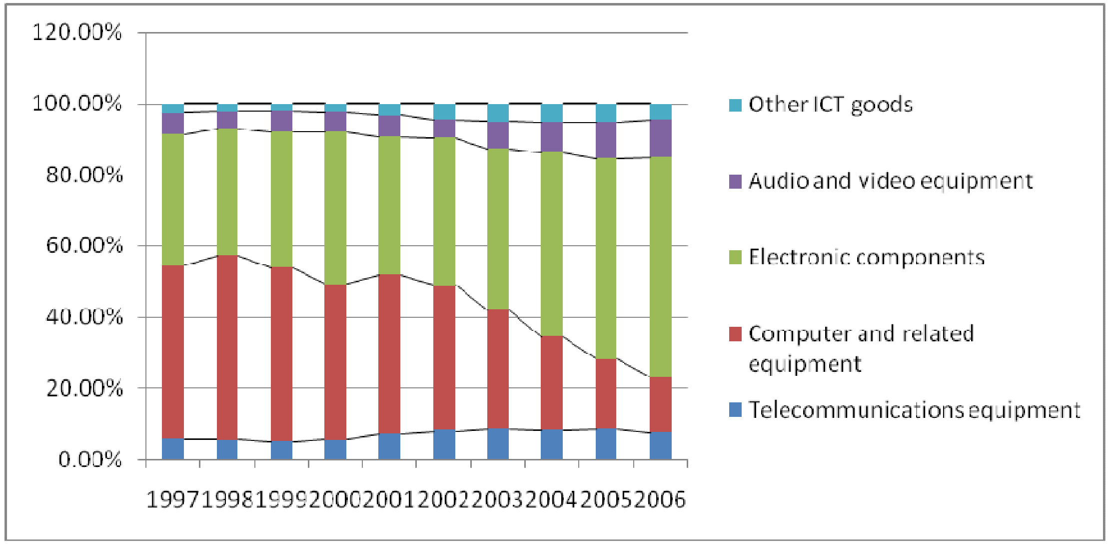
Year	2002			2003			2004			2005			2006		
The categories relating to ICT Goods	exports	imports	trade balance	exports	imports	trade balance	exports	imports	trade balance	exports	imports	trade balance	exports	imports	trade balance
Telecommunications equipment	146,592	74,475	72,117	168,754	71,378	97,377	178,464	73,257	105,207	185,051	88,710	96,341	187,620	86,993	100,627
Computer and related equipment	747,842	263,515	484,327	646,309	204,580	441,729	566,328	189,809	376,519	412,984	161,426	251,558	384,536	148,836	235,700
Electronic components	755,358	758,919	-3,562	884,085	821,123	62,962	1,131,677	972,897	158,779	1,209,599	1,004,054	205,544	1,541,020	1,120,310	420,710
Audio and video equipment	95,656	27,758	67,897	148,897	40,435	108,462	182,577	41,375	141,201	221,199	49,059	172,141	259,186	51,225	207,962
Other ICT goods	83,555	104,979	-21,424	98,880	115,822	-16,941	114,153	183,521	-69,368	109,388	148,544	-39,155	114,169	177,013	-62,844
Total ICT Goods	**1,829,002**	**1,229,647**	**599,356**	**1,946,926**	**1,253,337**	**693,588**	**2,173,198**	**1,460,860**	**712,338**	**2,138,221**	**1,451,792**	**686,429**	**2,486,531**	**1,584,377**	**902,155**

Note: ICT subsectors refer to the classification of ICT sectors defined by UN, which is in line with the OECD definition.
Source: Complied by CIER.

Graph 6: Export Structure of Taiwan's ICT Sector



(A) In Terms of ICT Export Values



(B) In Terms of Ratio to ICT Exports

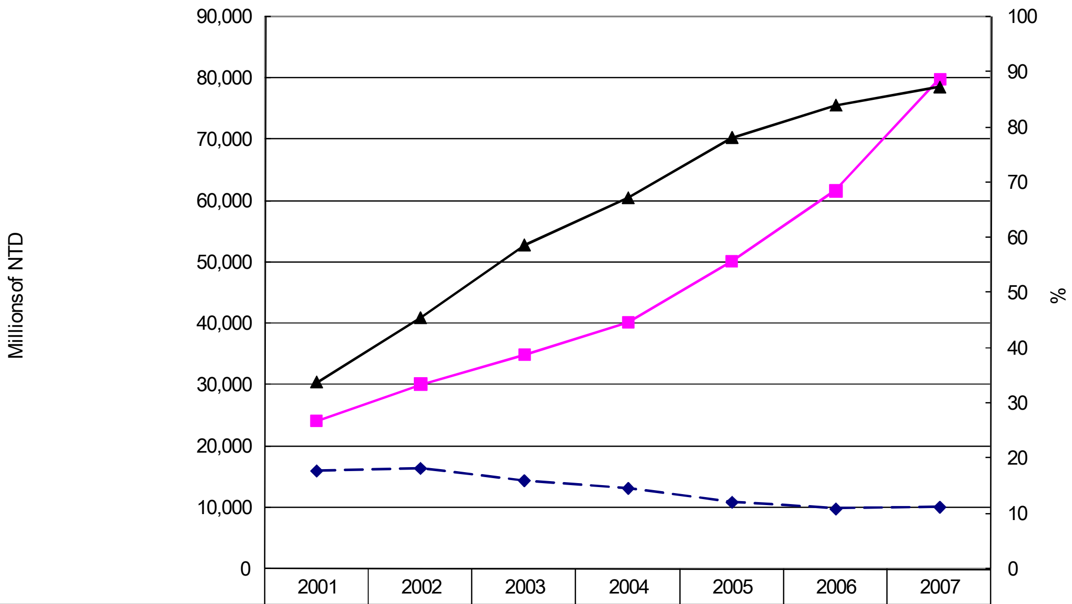
Source: Compiled by CIER.

Table 3: Share of Incremental Production Values over 2001-2006 for the Non-Traditional Sectors in Taiwan

Sector (at the 3-Digital Level)	Share of Incremental Production Values over 2001-2006	Accumulated Share
Semiconductors Manufacturing	34.21%	34.21%
Optoelectronic Materials and Components Manufacturing	33.58%	67.79%
Other Electronic Parts and Components Manufacturing	10.75%	78.53%
Other Non-Traditional Manufacturing	8.41%	86.95%
Computers and Peripheral Equipment Manufacturing	7.18%	94.13%
Bare Printed Circuit Boards Manufacturing	5.87%	100.00%

Source: Data taken from the Industry, Commerce and Service Sector Census, compiled by CIER.

Graph 7: Offshore Production Ratio of Taiwan's Information and Communications End Products Manufacturing



	2001	2002	2003	2004	2005	2006	2007
Value of exports orders received	24,249	30,180	35,003	40,295	50,174	61,734	79,856
Value of actual exports	16,038	16,454	14,463	13,205	10,974	9,884	10,167
Offshore production ratio (%)	33.86	45.48	58.68	67.23	78.13	83.99	87.27

Source: Data taken from Department of Statistics, Ministry of Economic Affairs and Department of Statistics, Ministry of Finance, compiled by CIER.

1.2 The Major Sub-Sectors of Taiwan's ICT Industry

1.2.1 The Global Production Network and the ICT Device Industry

The global production network (GPN) is a production scheme where various stages of a manufacturing process are undertaken at different geographic locations where they can be carried out most efficiently (UNCTAD, 2005). In many cases, ICT products are characterised by modularisation, even in terms of their internal parts and components, involving a set of jointly-consumed interdependent products. On the basis of the network effects and product compatibility, successful innovations for ICT products often entail intensive interfaces between multiple actors with different knowledge and skills bases. By implication, not only does such an innovation often result from the collective efforts of inter-related firms, but it also demonstrates that the value chain does not need to be completely internalised within individual firms. Therefore, industrial competition takes place between rival technological and production networks that contain a multiplicity of differentiated firms, led by such brand marketers (or network flagships) as Dell and HP, rather than simply between vertically-integrated oligopolies.

ICT product innovations in the global production and innovation network involve an assortment of knowledge related to various stages of the value chain, taking place at different firms and locations. On one hand, the brand marketers tend to focus their R&D mainly on product concept initiation and product architecture, the scheme by which a product's arrangement of functional elements, the mapping from functional elements to physical components, and the specification of the interfaces among interacting physical components is defined (Ulrich, 1995). On the other hand, their Taiwanese subcontractors are devoted to component technologies, "design to order" and design for manufacturing. In addition, concurrent development between all these parties, facilitated by the application of information and communication technologies, has increasingly become the norm in the industry. For example, Mitac, a leading PC producer in Taiwan, has set up a "collaborative product commerce" (CPC) mechanism for online joint product design, incorporating an intra-link that enables its subsidiaries and partners to use the same design tools for joint product design and development. The process ranges from product definition to product R&D and product modularisation, and not only helps to reduce the R&D cycle time for Mitac and its partners, but is also an essential element in the coordination of the subsequent production, assembly, delivery and repair and maintenance activities.

With some of the Taiwan's ICT firms having scaled down, or even having hollowed out their manufacturing operations in Taiwan, shifting them towards China and elsewhere, it may in fact become necessary for them to increasingly rely on their Chinese subsidiaries in order to engage in manufacturing-related R&D. This seems more likely in the case where the de-linking of R&D and manufacturing is feasible (Chen, 2004). As a matter of fact, the majority of Taiwanese ICT OEM/ODM vendors tend to conduct R&D, product design and pilot run mainly in Taiwan, while leave the mass production jobs to be undertaken at their overseas plants.

On balance, Taiwan's ICT device industrial clusters have co-evolved with their international counterparts, hence local agglomeration alone can no longer adequately account for the dynamics of Taiwan's ICT device industry, because the way in which the global PC industry is organised has changed. As a result, the offshore production of Taiwan-based ICT device firms has now substantially outweighed their domestic production, with China accounting for 89% of total production in 2007.

1.2.2 Vertical Disintegration and Virtual Integration: The IC Industry

The global IC industry is currently dominated by firms from the USA, Japan, Korea, and Taiwan, with their world-wide rankings showing in this order. Of interest is the fact that the industry in Taiwan differs from that in the other three in several significant ways. Unlike Korea, which highly specialises in the dynamic random access memory (DRAM) segment, Taiwan produces a much wider variety of IC chips, and dominates in foundry services, capturing around 64% of the global market share. In addition, in contrast to the vertically integrated conglomerates that dominate the industry in Korea and Japan, Taiwan's IC industry consists of many small firms specialising in a narrow range of the value chain, such as IC design, mask production, foundry service, packing, and testing. Taiwan's flock of more than 270 IC design houses put it second behind only the USA in that segment. In a sense, Taiwan's IC industry is organised as an industrial network system with a strong connection to Silicon Valley, the world-wide centre of the IC market and IC technology (Saxenian, 1997; Kim and Tunzelmann 1998).

The development of Taiwan's IC industry has been driven by organisational innovation, with foundry services pioneered by TSMC in 1987 as a market niche to specialise in production for external customers. By disintegrating the IC value chain, the emergence of foundry services in Taiwan facilitated the proliferation of small and medium-sized firms engaged in other market segments, such as IC design, testing, and packaging,[8] which gave rise to a balanced and vertically disintegrated industrial structure. In particular, fabless IC design houses proliferated in Taiwan in part because access to external fabrication capacity lowered the barriers to entering the IC design market. In addition, the concentration of IC and computer-related firms in the Hsinchu Science Park generated agglomeration effects that allowed those firms to exploit the benefits of proximity and outsourcing. Therefore, even though they specialise in one segment of the value chain or another, IC firms in Taiwan are networked by social and business connections.

Moreover, Taiwan's IC industry is closely connected with the global industry centre in Silicon Valley. Taiwan's strength lies in its foundry services, which depends on substantial investment in fabrication capacity. The U.S. IC firms, on the other hand, tend to concentrate on R&D, design, and marketing functions, which are backed up by access to Taiwan's foundry service capacity. In fact, most of the top ten fabless makers[9] in the USA have been clients of Taiwan's foundries. Both TSMC and UMC, the world's leading foundry service providers, share their resources and information with their customers, considering them as partners. This sharing of resources and information not only facilitates the development of close long-run relationships with customers, but also helps reduce the uncertainty on both sides over technology development.

Another facet of the connection between the IC industry in Taiwan and in the USA is the intensive interchange between specialists in both countries. Underlying this exchange are Taiwanese and Chinese expatriates, who have played important roles in establishing the trans-Pacific social and business networks that have proved crucial in connecting Taiwan's production system with advanced market knowledge and technology (Saxenian, 1997; Kim and Tunzelmann 1998). The fact that the IC industrial systems in both Taiwan and Silicon Valley are decentralised and network-based also facilitated the interchange. This type of

[8] In 2007, there were 13 IC (both foundry and DRAM) manufacturers, 270 IC design houses, 8 wafer manufacturers, 34 IC packaging firms, and 36 IC testing firms in Taiwan.

[9] For example, they include Qualcomm and nVidia.

industrial system encourages the pursuit of multiple technical opportunities, heavy reliance on outsourcing, and inter-organisational knowledge flows (Sanxenian, 1997). The similarity in industrial structure makes networking between Silicon Valley and Hsinchu Science Park much easier and more intensive.

In addition, GPNs have had similar implications for the IC industry. By disintegrating the IC value chain, the initial emergence of foundry services in Taiwan facilitated the proliferation of small and medium-sized firms engaged in other market segments, such as IC design, testing and packaging, giving rise to a vertically disintegrated industrial structure. Moreover, the emergence of system-on-a-chip (SOC) has induced the modularisation of various design technologies, or silicon intellectual properties (SIPs), which can be used repetitively as the main building block for SOC designs. This trend has given rise to 'chipless' IC firms, acting as pure providers of SIP without owning a fab, or even a chip (like ARM in the UK), leading to further disintegration of the industry (Chen, 2002). As a result, IC design and production has come to resemble SIP assembly (see Graph 8).

Although most SIPs are owned by IDMs (Integrated Device Manufacturers), fabless firms and chipless IC firms, foundry service providers are the natural places to verify the value and 'fabricability' of SIPs. Therefore, in order to go through the entire value chain, the industry is required to bring together a variety of industry players, including chipless firms, design service providers, IC designers, electronic design aid (EDA) tool providers, and foundry and packaging firms, who are likely to be located in a number of different nations. Added to this, the technology complexity of SOC may heighten the pressure of "time-to-market" and demand a "collegial" partnership among a network of technology and business parties. Within this process, there is also an increasing demand for new "platforms" in such areas as design tools and design services in order to achieve cost-effective system integration because SOC involves both system complexity and a need for outsourcing. The production networks in the industry are hence global, or at least international, in nature. As a result, the IC industry will probably witness the proliferation of new industrial players and business functions, with some of them reinforcing the existing ones, and the industry as a whole may hence become more physically disintegrated but virtually integrated.

It should be noted that while Taiwan has been among the major FDI investors in China (see Section 3.2.1 for details), the Taiwanese government has maintained certain regulatory control over IC sector's offshore investment towards China, particularly regarding IC manufacturing and IC design. Right now, only a few IC manufacturers are allowed to relocate a limited part of their manufacturing capacities to China, but low-end packaging and testing firms have substantially expanded their operations in China. Therefore, Taiwanese IC firms' investment in China is relatively limited in scale.

1.2.3 A Global Oligopolistic Player: The LCD Industry

While LCD panel was first invented in the USA, it was Japanese who had managed to commercialise the product, applying initially to handheld electronic devices. The LCD technology began to take root in Taiwan in the early 1990s, thanks to initial technology transfer from the USA and a government R&D program performed by the ITRI. However, it was technology transfer from Japan after the Asian Financial Crisis in 1997 and the growing significance of Taiwan-based firms in the production of LCD monitors and notebook computers that had provided ammunition to the burgeoning development of the LCD industry in Taiwan. The government took advantage of this trend by promoting the so-called "Two-Trillion Industries", from the second half of the 1990s onwards. In addition to R&D initiatives and the tax credit scheme, a few other science parks have been established to accommodate a growing number of industrial players in the related sub-sectors. This has contributed in part to the fast development of the Southern Taiwan Science Park in Tainan and Central Taiwan Science Park in Taichung. In fact, both of these two science parks are dominated by the IC and LCD industries, though differing in degree between them. Arguably the development of the two new science parks has much to do with the relocation of production capacities by the major players located in the Hsinchu Science Park.

Right now Taiwan and Korea are engaged in head-to-head competition to be the global leader in the production of LCD panels. However, both Korea and Japan are ahead of Taiwan in terms of technology development and production deployment for large-sized LCD panels. In addition, the players in these two countries are diversified conglomerates with global brand-names, such as Samsung and LGD (LG Display) in Korea and Sony in Japan, which may facilitate them to exploit scope economy, especially when it comes to the manufacturing and marketing of LCD TVs. In contrast, the LCD industry in Taiwan is largely featured by vertical disintegration, except for the fact the local leading players, such as AUO and ChiMei also produce LCD monitors and LCD TVs with own brands.

LCD panels were initially made for handheld devices, monitors and notebook computers, but are recently for LCD TVs. The rise of China as a major production site and exporter for ICT end products, particularly monitors and notebook computers[10] has triggered the Taiwanese LCD producers to relocate part of their production processes to China.[11] However, this relocation process was controlled by an official ban from moving the upstream manufacturing processes (array and cell production, the core processes) towards China. As a result, the upstream manufacturing processes in the LCD Industry have been kept in Taiwan as well as in Korea and Japan, though some of the downstream processes have been relocated to China stepwise (see Graph 9). Initially, it was LCM (LCD Modules) which came to China first in order to exploit geographical proximity to the production sites of ICT end products and cheap labour costs. More recently, some of the Taiwan-based LCD producers have moved such upper stream processes as Backlight Units and Bond Drivers to Glass & PCB to China.

However, the recent financial "tsunami" has marked a turning point of the cross-strait relationship, which may bring about the reconfiguration of the cross-border production network for the LCD sector in East Asia. Taiwan's ICT industries, those of DRAM and LCD in particular were hit severely by the Financial Tsunami because of the "Bullwhip effect[12]", but have managed to get out of the difficult situation thanks to the so-called cross-strait "Peace Bonus effect". Specifically speaking, in response to the global economic downturn, China has not only implemented a demand-stimulus package by providing subsidies to the consumption of such goods as TVs and computers, but also made deliberate procurements from the Taiwanese suppliers of LCD panels. As a result, the LCD makers in Taiwan have got out of the industrial slump. Nonetheless, having demonstrated the strength of its domestic consumption, China unveiled its plan to establish indigenous LCD production capacities, going beyond that of LCM. Therefore, the major players from Taiwan (ChiMei and AUO), Korea (Samsung and LGD) and Japan (Toshiba and Sony) have jumped on the bandwagon by

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10 The Taiwanese government lifted the ban on the local NB producers' investment towards China in 2001.

11 China's local firms began producing LCD panels in the late 1990s and early 2000s through technology transfer of old-generation panels and the adoption of fabs from overseas, but made slow progress.

12 The Bullwhip effect refers to the amplified variations between demand and inventory as one moves upstream in the supply chain, further from the customer.

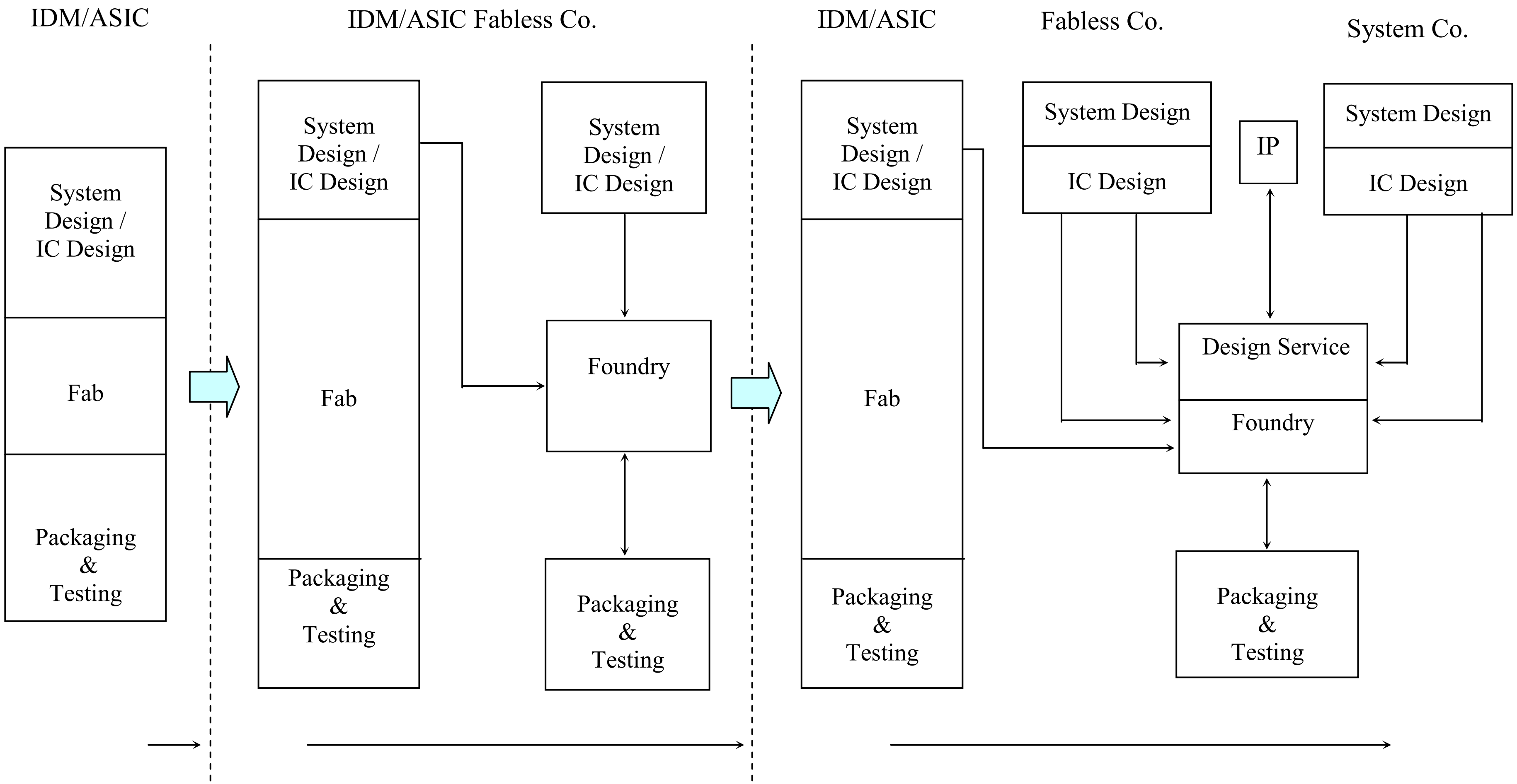
forming partnerships with Chinese TV makers. It is hence very likely that China will soon join the league of LCD producers.

1.3. Summary

Taiwan is indeed highly specialised in ICT, in terms of manufacturing GDP, exports, and more importantly R&D expenditures. In addition, Taiwan's ICT industry as a whole is featured by vertical disintegration, with the individual constituent firms specialising in one segment or another. Despite its well-documented feature of local clustering, Taiwan's ICT device industrial clusters have co-evolved with their international counterparts, hence local agglomeration alone can no longer adequately account for the dynamics of Taiwan's ICT device industry. Because of the formation of the GPN, domestic production in Taiwan tends to concentrate on such "intermediate goods" as IC and LCD, most of which are exported to overseas manufacturing hubs of ICT end products, particularly China. However, for most of the ICT firms, particularly the IC and LCD manufacturers, their R&D bases remain largely located in Taiwan. This together with the IC design industry makes Taiwan as an innovation hub for the global ICT production network.

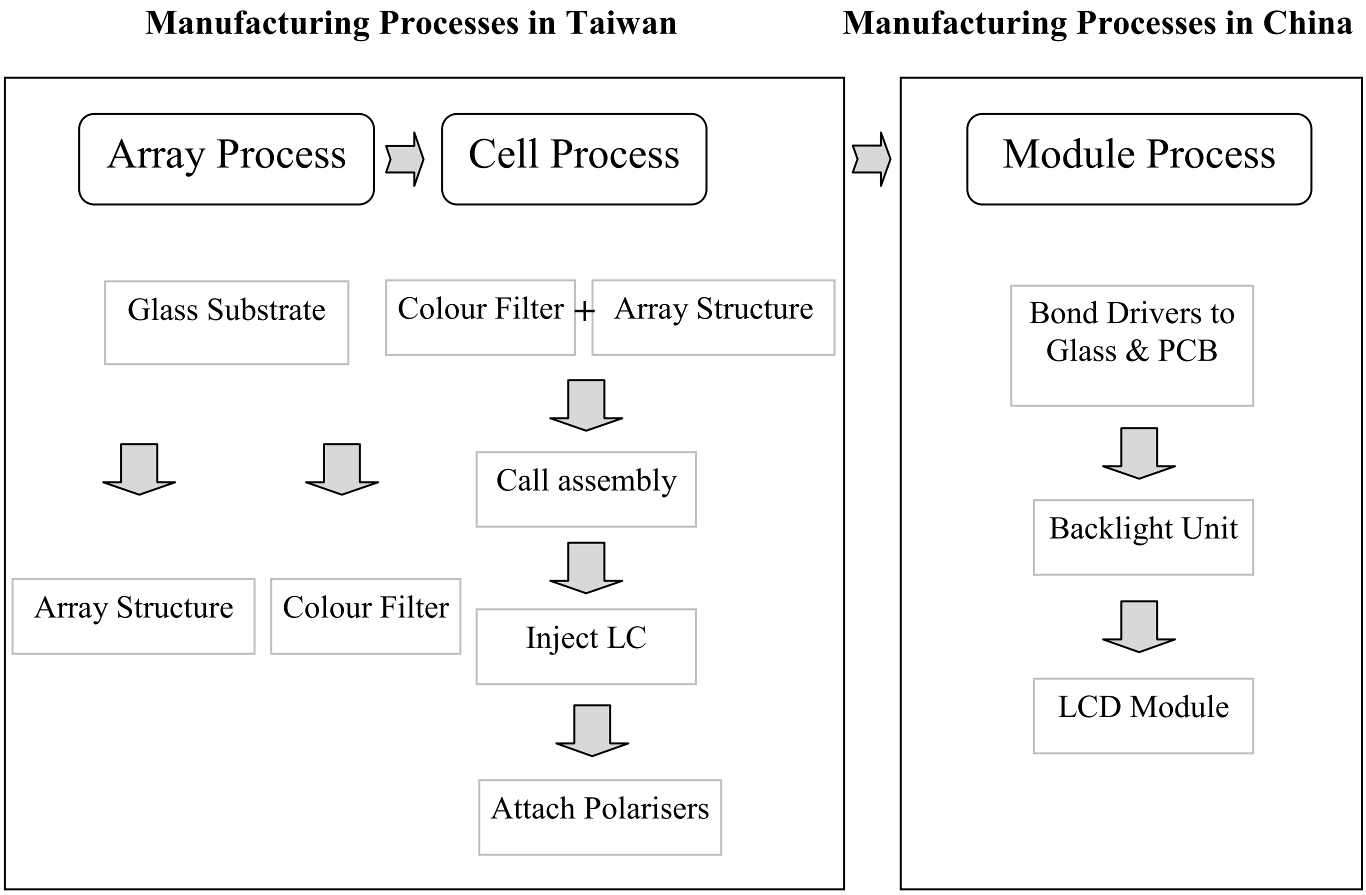
Based on the above analyses, one can better understand the role played by the science parks in Taiwan, particularly regarding the evolution of the Hsinchu Science Park (HSP). This Park is a designated science park, actively promoted by the government. The PC and IC subsectors were among the early residents at the park. Particularly, two leading foundries, UMC and TSMC were spin-offs from the ITRI located nearby. In addition, the formation and evolution of the park arguably has had much to do with the development of the ICT industry on the international scale, as well as in Taiwan. This evolutionary process is evident in terms of the sectoral breakdown of realised capital formation and revenues in the HSP. Both the IC and opto-electronic (mainly LCD) sectors have registered a growing trend in terms of the realised capital formation in the park. In 2005, the IC industry accounted for 79.82% of the realised capital formation in the park, as compared to 31.49% in 1986, while the share for the opto-electronic sector reached 10.28%, from 5.62% in 1986. In contrast, the computer & peripheral equipment industry's share of realised capital formation had declined from 25.13% in 1986 to 6.91% in 2005. Two new science parks, the Southern Taiwan Science Park (STSP) and the Central Taiwan Science Park (CTSP) were also established around the late 1990s, and have grown very fast since then. The establishment of these two science parks was driven by an intention to develop more diversified high-technology sectors other than the ICT industry, but does not live up to this initial expectation. In the end, both of these two science parks are dominated by the IC and LCD industries, though differing in degree between the two parks. Arguably the development of the two new science parks has much to do with the relocation of production capacities by the major players located in the Hsinchu Science Park.

Graph 8: The Trend towards Disintegration of the IC Industry



Source：Initially from Foundry Watch, TSMC; adapted from Chen (2002).

Graph 9: The Current Cross-Strait Division of Labour in the LCD Industry



Source: Based on materials provided by IEK, ITRI.

CHAPTER 2. ICT SECTOR: COMPANY LEVEL ASSESSMENT

2.1. ICT Scoreboard – Top 20 Firms

This chapter sets out to examine Taiwan's ICT industry at the firm level. We begin by identifying the leading firms at the subsector level, with reference to top 20 firms in terms of sales, R&D expenditures, and US patents acquired, as summarised in Table 4. The subsectors are classified into three broad sectors, including the IC, LCD manufacturing, and computing/communications subsectors. The IC subsector is also broken down into IC manufacturing, IC design, and IC packaging & testing, while the computing/communications subsector comprises of brand-name firms, OEM/ODM manufacturers, specialised component suppliers, and service providers.

By sales,[13] out of the top 20 firms, the computing/communications subsector outnumbers the rest of the subsectors, with six firms operating as OEM/ODM manufacturers, followed by four specialised component suppliers. In particular, Hon Hai Precision (also known as Foxconn), Quanta and Asus are among the top three firms. However, when it comes to R&D expenditures, the IC subsector stands out, with six leading firms serving as IC manufacturers (mainly foundry and DRAM manufacturing). In addition, Mediatek, an IC design house takes the lead in R&D investment, only secondary to TSMC, the global foundry leader. Another two IC design houses, Realtek (the 17th) and Novatek (the 18th) are also listed as Top 20 R&D investors. Of note is the fact that HTC, a handset producer with own brand-name is ranked as the third leading R&D investing firm, while Chunghwa Telecom (CHT) is the only service provider that can join the league of Top 20 in terms of R&D expenditures.

Referring to the number of the US patents granted,[14] the leading firms in the individual subsectors stand out, for example, TSMC (the 2nd) and UMC (the 9th) in IC manufacturing, Mediatek (the 4th) and VIA (the 5th) in IC design, AUO (the 3rd) in LCD manufacturing, Hon Hai (the 1st) and Inventec (the 8th) in OEM/ODM manufacturing, and Foxlink (the 6th) and Delta (the 10th) in specialised component manufacturing. Even two IC packaging & testing firms, ASE (the 14th) and IST (the 20th) can take their positions in this league table.

Table 5 lists Taiwan's top 20 ICT firms by R&D investment. TSMC and Mediatek take a substantial lead in this regard, with TSMC investing US$629.35 million and Mediatek investing US$480.05 million in 2008. They are followed at a distance by HTC (US$305.16 million), Hon Hai (US$291.63 million), and UMC (US$260.15 million). In terms of R&D intensity (R&D/sales), the IC design and IC manufacturing groups stand out. In particular, the R&D intensity of two IC design houses, Mediatek and Realtek is so high as 22.24% and 18.78% respectively. For the IC manufacturing group, two foundry firms, TSMC (6.16%) and UMC (8.86%), three DRAM manufacturers, Nanya Technology (17.62%), Powerchip Semiconductor (6.53%) and ProMOS (8.23%), and an ASIC IC manufacturer, Macronix (11.69%) all have a relatively high R&D intensity. HTC, a technological leader in the handset sector also spends 6.30% of its sales in R&D. In contrast, the firms in the computing/communications and LCD manufacturing subsectors tend to have a lower R&D intensity, even for Hon Hai (0.62%).

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[13] For the details on the sales of the Top 20 ICT firms in Taiwan, please see Appendix.

[14] By nature, patenting is a location-specific decision. Since the Taiwanese ICT firms have had strong connections with the USA in terms of market and technology, it is useful for our analyses to refer to the US patents granted.

Table 5 and Table 6 provide information on the number of total US patents and utility patents[15] respectively granted to top 20 ICT firms in Taiwan. Hon Hai is the far ahead leader, acquiring 640 US patents in 2008, and followed by TSMC (368), AUO (182), Mediatek (166), and VIA (163; an IC design house). However, the US patents acquired by these four firms are almost utility patents. In addition, the top 10 firms in the list are all granted more than 100 US patents. Two IC packaging and testing firms, Advanced Semiconductor Engineering and International Semiconductor Technology also join this league table, acquiring 59 and 48 US patents respectively.

Based on the above information on top 20 firms scoreboard of sales, R&D, and US patents, we go further to examine the share of the individual subsectors (see Graph 10, Graph 11 and Graph 12). According to Graph 10, the OEM/ODM manufacturer group accounts for more than 50% (51.27%) of the combined sales of the top 20 firms. In addition, about three quarters (75.33%) of the combined sales can be attributed to the computing/communications subsector as a whole (including brand-name firms, OEM/ODM manufacturers, and specialised component suppliers). The share for the LCD manufacturing and IC manufacturing subsectors is just 17.76% and 6.92% respectively.

In sharp contrast, when it comes to R&D expenditures, the IC subsector (including manufacturing and design) stands out, accounting for 50.28% of the combined R&D expenditures invested by the top 20 firms (Graph 11). Cross-checking Graph 10 and Graph 11, one can also observe that the computing/communications subsectors as a whole tends to have a relatively low R&D intensity.

However, in terms of the individual subsectors' share of US patenting (Graph 12), the sectoral distribution is not so biased towards the IC sector. About 48.25% of the total patents granted to the top 20 firms can be accounted for by the computing/communications subsector as a whole; and out of this percentage, 32.06% can be attributed to the OEM/ODM manufacturers, and 11.13% to the specialised component suppliers. In addition, the patent share for the IC manufacturing group is 22.55%, and 14.20% for the IC design group.

The picture portrayed above gives rise to two important questions. First of all, why do the leading IC manufacturers, and even the IC design houses invest so much in R&D? A quick answer to this question is that the IC manufacturers, particularly the two foundry firms are approaching the technological frontiers, entailing a substantial increase in R&D investment. For example, UMC and TSMC are currently about half a year or a year behind the global leader, Intel, in terms of technological milestones. Even though the DRAM manufacturers in Taiwan rely much on technology transfer from the global leaders, such as Micron and Elpida, they still have to invest a lot in R&D in order to quickly absorb the latest generations of technologies. A second question is about the relatively high share of US patents granted to the OEM/ODM manufacturer group and the specialised component supplier group, compared to their lower R&D intensity. This may have much to do with the nature of the GIN, for which part of the network flagships' innovation offshoring tends to take the form of farming out to layers of specialised suppliers. We shall elaborate further on these two issues in the next chapter.

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[15] USPTO classifies patents into utility patents and design patents. A utility patent protects any new invention or functional improvements on existing inventions, while a design patent protects the ornamental design, configuration, improved decorative appearance, or shape of an invention. (http://www.wisegeek.com/what-is-the-difference-between-a-design-patent-and-a-utility-patent.htm).

Table 4: Taiwan's ICT Scoreboard: Top 20 Firms by Sales, R&D Expenditures, and US Patents Granted

Subsector		Sales (2007)	R&D Expenditures	US Patents Granted
IC	IC Manufacturing	TSMC (7), UMC (16)	TSMC (1), UMC (5), Nanya (6), Powerchip (15), Macronix (19), ProMOS (20)	TSMC (2), Macronix (7), UMC (9)
	IC Design		Mediatek (2), Realtek (17), Novatek (18)	Mediatek (4), VIA (5), Realtek (13)
	IC Packaging & Testing			ASE (14), IST (20)
LCD Manufacturing		AUO (4), Chi Mei (8), Innolux (12), CPT (13)	Chi Mei (7), AUO (11), CPT (13)	AUO (3), CPT (12), Innolux (17)
Computing/ Communications	Brand-name	Asus (3), Acer (6), HTC (15)	HTC (3), Asus (9)	Hannspree (11), Asus (19)
	OEM/ODM	Hon Hai (1), Quanta (2), Compal (5), Wistron (9), Inventec (10), Qisda (14), Mitac (20)	Hon Hai (4), Wistron (8), Quanta (10), Compal (12), Inventec (14)	Hon Hai (1), Inventec (8), Quanta (15), Qisda (18)
	Specialised Component Supplier	Lite-on (11), Foxconn (17), Micro-Star (18), Elitegroup (19)		Foxlink (6), Delta (10), Foxconn (16)
	Service Provider		CHT (16)	

Note: The figures in the parentheses refer to ranking for the individual firms.
Source: Compiled by CIER.

Table 5: Taiwan's ICT Scoreboard: Top 20 Firms by R&D Expenditures, 2008

Company	R&D Expenditures (Million US$)	R&D Intensity*	Ranking (2008)	Ranking (2007)
TSMC	629.35	6.16%	1	1
Mediatek	480.05	22.24%	2	3
HTC	305.16	6.30%	3	13
Hon Hai Precision (Foxconn)	291.63	0.62%	4	7
UMC	260.15	8.86%	5	2
Nanya Technology	202.96	17.62%	6	6
CMO (Chi Mei Optoelectronics)	202.24	2.06%	7	4
Wistron	197.33	1.47%	8	10
Asustek	174.07	2.20%	9	5
Quanta	171.26	0.71%	10	11
AUO	169.28	1.26%	11	9
Compal	150.01	1.18%	12	14
CPT (Chunghwa Picture Tubes)	135.73	4.26%	13	8
Inventec	117.24	1.05%	14	20
PSC (Powerchip Semiconductor)	109.41	6.53%	15	17
CHT (Chunghwa Telecom)	100.00	1.69%	16	16
Realtek	99.77	18.78%	17	21
Novatek	90.52	10.90%	18	29
Macronix	86.28	11.69%	19	19
ProMOS	80.07	8.23%	20	18

*: R&D intensity= R&D/Sales.

Note: The figures in the parentheses refer to ranking for the individual firms. The average exchange rate between US$ and NT$ in 2008 was about 31.517.

Source: Compiled by CIER.

Table 6: Taiwan's ICT Scoreboard: Top 20 Firms by US Patents Granted, 2008

Ranking	Assignee of Company	No. of Total US Patents Granted (2008)
1	Hon Hai Precision (Foxconn)	640
2	TSMC	368
3	AUO	182
4	Mediatek	166
5	VIA	163
6	Foxlink (Cheng Uei Precision)	150
7	Macronix	136
8	Inventec	134
9	UMC	120
10	Delta	102
11	Hannspree	87
12	CPT (Chunghwa Picture Tubes)	70
13	Realtek	64
14	ASE (Advanced Semiconductor Engineering)	59
15	Quanta	58
16	Foxconn Technology	56
17	Innolux Display	56
18	Qisda	55
19	Asustek	53
20	IST (International Semiconductor Technology)	48

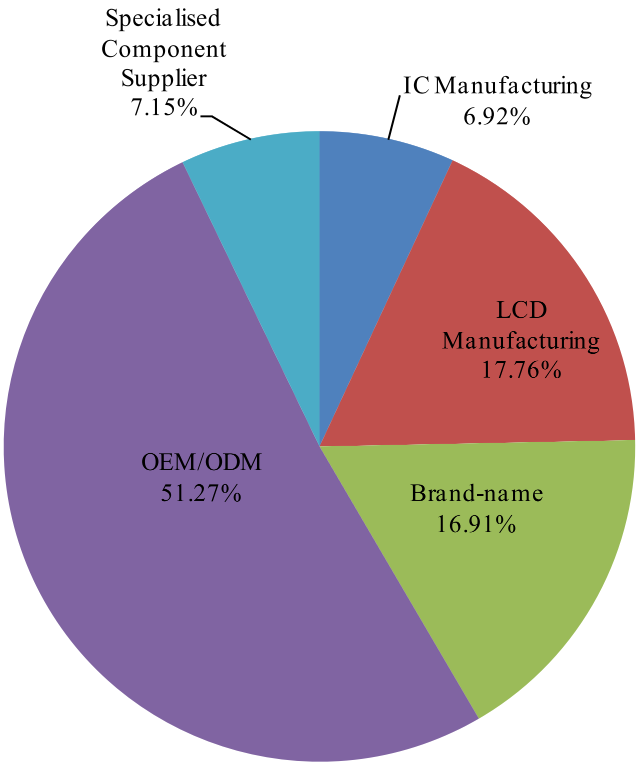
Note: The figures in the parentheses refer to ranking for the individual firms.
Source: Data taken from USPTO and compiled by CIER.

Table 7: Taiwan's ICT Scoreboard: Top 20 Firms by US Utility Patents Granted, 2008

Ranking	Assignee of Company	No. of US Utility Patents Granted (2008)
1	Hon Hai Precision (Foxconn)	498
2	TSMC	366
3	AUO	182
4	Mediatek	166
5	VIA	163
6	Macronix	136
7	Inventec	131
8	UMC	119
9	Delta	90
10	CPT (Chunghwa Picture Tubes)	70
11	Foxlink (Cheng Uei Precision)	64
12	Realtek	64
13	ASE (Advanced Semiconductor Engineering)	59
14	Qisda	55
15	Innolux Display	51
16	Asustek	50
17	IST (International Semiconductor Technology)	48
18	Sunplus Technology	44
19	Himax Technologies	43
20	Asia Optical	42

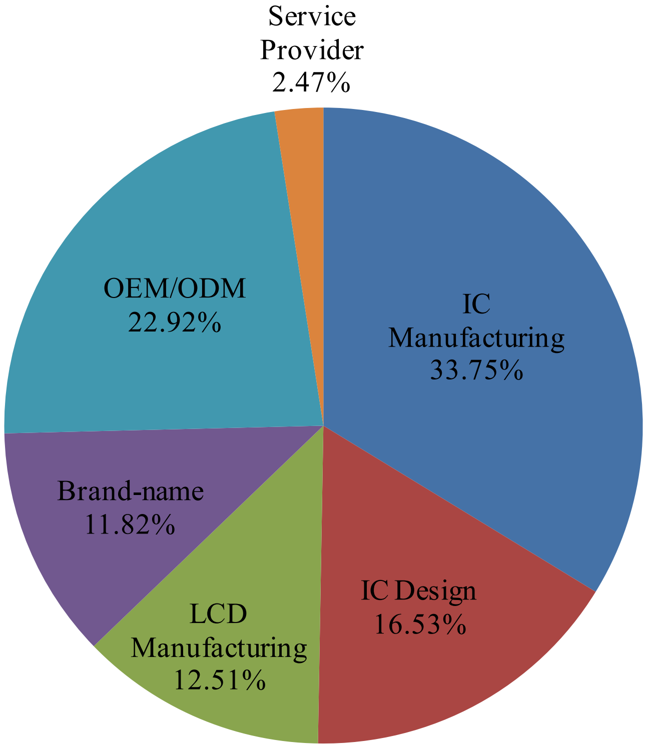
Source: Compiled by CIER.

Graph 10: Sales of Top 20 Firms: Share of Individual Subsectors



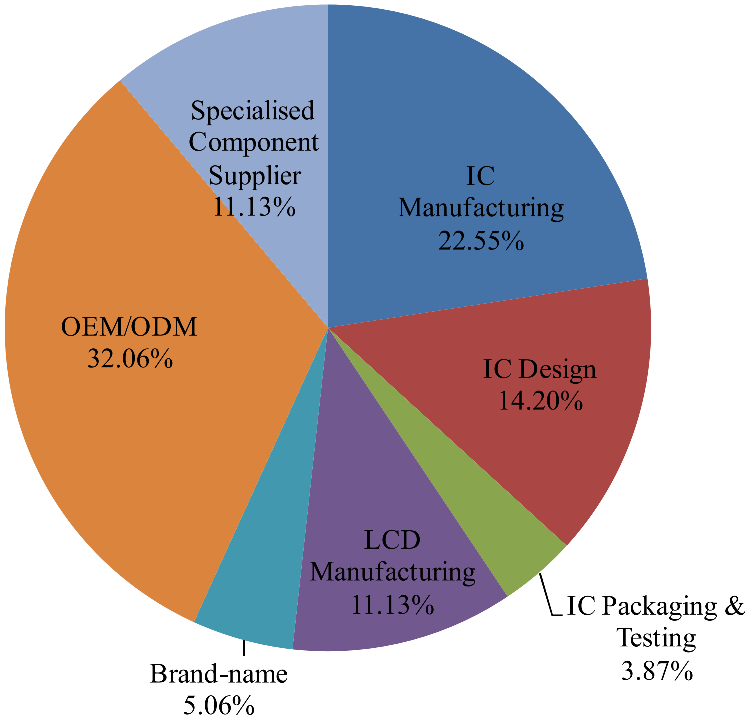
Source: Compiled by CIER.

Graph 11: R&D of Top 20 Firms: Share of Individual Subsectors



Source: Compiled by CIER.

Graph 12: US Patents Granted to Top 20 Firms: Share of Individual Subsectors



Source: Compiled by CIER.

2.2. Case Studies

Having highlighted the characteristics of the top 20 ICT firms in Taiwan, this section now presents four case studies.

2.2.1 TSMC

Table 8: Basic Profile of TSMC

Year of Foundation and operations	1987; Outside Taiwan with wholly-owned subsidiary WaferTech in the U.S.; TSMC (Shanghai) China; and its joint venture fab SSMC in Singapore
Main Products	Semiconductor foundry and related services
Employees (2007)	20,555
Sales (2008)	US$10,216.70 million
R&D (2008)	US$629.35 million
R&D/Sales (2008)	6.16%

Source: Compiled by CIER.

TSMC may be regarded as a major catalyst in the evolution of the global IC industry. The company was created in 1987 to function as a dedicated foundry service provider, simply carrying out contract fabrication work for global customers ranging from IC design houses to world-leading IDMs. Therefore, customer relationship management, as well as fabrication capacity and capability, were always central to TSMC's operations, in which technological development and e-commerce have come to play an increasingly important role.

TSMC was a spin-off from the ITRI, which had managed to master the technology transferred from RCA. As the global leader in foundry, capturing about 60~65% of the world-wide market share, TSMC has approached the technological frontiers, almost on a par with the global IC leader, Intel. Underlying this is the company's commitment to R&D, leading to a substantial number of US patents each year, as discussed in the above section. In 2008, TSMC's R&D expenditure (US$629.35 million) amounted to 6.16% of its sales. In addition, TSMC has been a member of Sematech, an international consortium of the semiconductor industry, and is currently working closely with the major members of Sematech on 450mm (the latest generation of technologies) project.

In the arms-length relationship between foundries and fabless design houses, it is essential to manage the flow of knowledge so as to facilitate a smooth and efficient transfer of new designs into production. This has been made possible by the design firm's adherence to "design rules" laid out by the foundry, namely, restrictions on the type of designs that will be manufactured in the foundry on a specific delivery schedule. These design rules are determined by the foundry's manufacturing capacity and capability. In light of this, foundries such as TSMC have become an essential node of the innovation network of new IC designs, which entails close interactions of knowledge and information between foundries and their customers. As a result, in 1996 TSMC initiated the concept of the 'virtual fab' in order to promote virtual integration with its customers by means of business-to-business (B2B) applications, thus rendering TSMC as the facilitator of its customers' supply chain management.

Apart from regular online business transactions, TSMC's B2B operations, under a total package of 'eFoundry' cover three major aspects: logistics, engineering and design collaborations. TSMC's eFoundry consists of a suite of Internet-based applications providing its customers with real-time support in wafer design, engineering and logistics, functioning as the master tool for the concept of the virtual fab. It currently supports five online services, including TSMC-Online, TSMC-Direct, TSMC-YES (Yield Enhancement System), TSMC-ILV (Internet Layout Viewer) and eJobView.

In terms of collaboration in logistics, TSMC-Online provides access to real-time production and logistics information updates in areas such as the status of wafer fabrication, assembly and testing, as well as order handling and shipping. As for engineering collaboration, TSMC-Online provides a variety of engineering capabilities, including interactive views of prototyping, lot status, yield analysis and quality reliability data. It is also empowered with design collaboration capabilities in support of customer access to important information needed during the design process. Aided by Design Service Alliance, as discussed below, TSMC-Online provides selected blocks of IP owned by third parties – these are robust design solutions that conform to TSMC's production technologies – which are then made available to designers.

In order to facilitate design collaboration, TSMC has also formed a Design Service Alliance with third parties. As mentioned earlier, the emergence of SOC has highlighted the importance of SIPs, and as a result, IC design has come to resemble the assembly of SIPs, from both internal and external sources. Design houses are also faced with the challenge of choosing from amongst a variety of library suppliers and Electronic Design Aid (EDA) tools. TSMC previously functioned as a pure-play foundry with limited design service capacity, but with Design Service Alliance, the company can now mobilise external resources to facilitate the design processes of its customers.

Design Service Alliance encompasses the four service areas that make up the IC design process - third party libraries, silicon-verified IPs, experienced IC designers and proven EDA software. A network of leading third party library vendors form the core of the Library Alliance enabling TSMC's customers to gain access to required technical services, leading edge process-specific technologies and documents on design requirements. IP Alliance encompasses a large category of silicon-verified and production-proven foundry specific IPs, which are useful for designers in IP assembly.

Through the Design Center Alliance, TSMC helps its customers to connect to a global network of qualified and experienced IC design centres in order to gain the necessary design expertise. Similarly, through the EDA Alliance, TSMC's design service engineers work with EDA Alliance members in order to deliver TSMC-specific technology files and design kits that may simplify its customers' design experience. In essence, the Design Service Alliance as a whole aims to provide TSMC's customers with total IC design solutions to accelerate cycle time from specification, through tape-out, to finished wafers. Both TSMC's customers and the key testing and packaging firms can gain access to the Design Service Alliance using TSMC-Online as the platform.

To summarise, whilst starting out as a stand-alone OEM foundry, TSMC has come to resemble a provider of integrated service packages covering a wide range of value chain management activities thanks to its extensive application of e-commerce as well as capabilities. For SOC to go through the entire value chain, wafer foundries hold a unique position in verifying as well as producing silicon-proven IPs. Therefore, the technological complexity of SOC may induce foundry firms to tighten networking relationships with the other types of industrial players. For example, in advancing the concept of virtual foundry, TSMC is championing a collegial win-win-win model, instead of the win-win customer/supplier relationship that currently prevails, which in turn, according to TSMC, may entail a "pay-for-performance" business model. In the same vein, UMC has also proposed a new "partnership foundry strategy". As a result, the industrial network in the IC industry will probably go further 'internationalised', bringing about escalating importance of cross-border technological linkages of the IC industrial clusters around the globe.

2.2.2 Mediatek

Table 9: Basic Profile of Mediatek

Year of Foundation and operations	1997; Headquartered in Taiwan and with sales and research subsidiaries in China, U.S., England, Demark, India, Japan, Korea and Singapore
Main Products	A fabless IC design house for wireless communications and digital multimedia solutions
Employees (2007)	N. A.
Sales (2008)	US$2,158.49 million
R&D (2008)	US$480.05 million
R&D/Sales (2008)	22.24%

Source: Compiled by CIER.

Mediatek, created in 1997, is a leading fabless IC company for wireless communications and digital multimedia solutions in Taiwan and even globally, with its annual revenues reaching NT$90.40 billion (about US$2,158.49 million) in 2008, from NT$40.05 billion in 2004 (about US$1,198.31 million). The company's R&D intensity was as high as 22.24% in 2008. Mediatek holds a unique position as a major catalyst in the proliferation in variety and fast expansion in quantity of Shan Zhai[16] handsets in China. Mediatek started its operations by designing and marketing chips for CD-ROM drives and further expands its operations to many sorts of consumer devices. Right now, the firm's chip set is still inside 50% of DVD players worldwide.

In 2004 Mediatek expanded into the territory of mobile phones by making "chipsets", a total solution incorporating processor-, radio- and other sorts of chips together with the necessary software. It is now widely perceived that Mediatek's solutions and business model have revolutionised the handset industry,[17] at least in China. Before Mediatek's entry, leading handset chip makers, such as Texas Instruments (TI), Broadcom, and Qualcomm worked closely with global oligopolistic brand marketers of handsets. Mediatek's total solutions, which have shortened the lead time to market from 9 months to about three months, make it much easier for handset makers to design and produce a wide variety of mobile phones. Together with its extensive technical supports in China, Mediatek has facilitated the explosive development of Shan Zhai handsets in China. It was estimated that about 150 million Shan Zhai handsets were produced in 2007, with 40% of them "exported" to such countries as India, Russia and Brazil. In spite of the notorious reputation of "bandit" phones, many of the Shan Zhai handsets in China are incorporated with local innovative ingredients and/or features, based mainly on Mediatek's total solutions.

In a sense, Mediatek's chipsets are in line with the trend of SOC in the IC industry, but the company's success also lies in its extensive technical support network in China. Prior to Mediatek's entry, there were precedents, such as Wavecom, a spin-off from Ericsson and Bellwave, a Korean total solution provider, and even Infineon and TI had chipsets catering to low-cost handset makers, but none of them have gone as far as Mediatek has. Not only was the timing ripe for Mediatek, but the company has built its strength on its extensive technical support network in China, proximity to customers and serving as local point of contact for everything relating to using its parts and chips from other vendors.

Thanks mainly to Mediatek's integrated solutions catering to low-cost and Shanzhai handset makers, technological barriers for designing and making handsets had been lowered, enabling Chinese Shanzhai handset makers to rapidly and frequently launch new products that fit well with diverse needs of the lower tiers of the market, overlooked by the incumbents. Therefore, while entering at a point somewhere between the growth and maturity stages, Mediatek has helped to create a massive market space which used to be underserved or underexplored (Chen and Wen, 2010).

Mediatek's ambition is not just providing chipset solutions for low-end handsets, instead the company has aimed at the smart phones market and even handsets for the Chinese indigenous 3G standard, TD-SCDMA. Recently Mediatek's solutions have been adopted by LG, a well-known Korean handset brand. In 2009, Mediatek has overtaken Broadcom to become the world's second-largest chip maker by revenue, secondary only to Qualcomm.

Ming-Kai Tsai, the Chairman of Mediatek, always emphasises that "low cost does not necessarily mean low technology because to achieve low cost may require integration of many functions together; hence high technology can be a means to achieve low cost". This

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[16] Some may refer Shan Zhai handsets to copy cats or "bandit" phones, but this is not necessarily true.

[17] Before Shanzhai handsets and Mediatek's total solutions, the global giants of mobile phones and such chip makers as Texas Instruments, Broadcom, and Qualcomm have not only controlled the technology of phone chip, the heart of a handset, but also owned the knowhow of supporting software.

statement can be endorsed by the fact that in the league table of Taiwan's Top 20 ICT firms, Mediatek ranks second in R&D, fourth in US patenting, as discussed in Section 2.1. In addition, Mediatek opts to focus on the so called "good enough market", trying to differentiate the company from the leading firms' practices of the "overshooting" of functions. This strategy coincides with Prahalad's (2006) ideas of "the Fortune at the Bottom of the Pyramid".

2.2.3 HTC

Table 10: Basic Profile of HTC

Year of Foundation and operations	1997; Main operations in Taiwan, with other R&D teams in the U.S. and a manufacturing site in China
Main Products	Touch phones, PDA phones, smart phones, mobile computers
Employees (2007)	5,569
Sales (2008)	US$4,843.83 million
R&D (2008)	US$305.16 million
R&D/Sales (2008)	6.30%

Source: Compiled by CIER.

Since its inception in 1997, HTC has pioneered the smartphone market through partnerships with Microsoft, Intel, Texas Instruments, Qualcomm; and some of the leading mobile operators in the advanced countries, including Orange, O2, T-Mobile, Vodafone, Cingular, Verizon, Sprint and NTT DoCoMo. The company is currently the world's largest producer of Windows Mobile Smartphones and Pocket PCs. Business Week ranked HTC as the second best performing technology company in Asia in 2007 and gave the firm the number three spot in its Global listing in 2006.

HTC is committed to driving the growth and capabilities of smartphone technology. Since its establishment, the company has developed strong R&D capabilities and pioneered first-of-its-kind products in the market. It has invested in a strong R&D team, accounting for 25% of the total headcount and ranking as the third leading ICT R&D investor in Taiwan, as discussed above. In 2008, HTC's R&D expenditure (US$305.16 million) amounted to 6.30% of its sales. In terms of internationalisation, part of the HTC's development team is based in Seattle, together with an acquisition of One & Co, a noted design firm based in San Francisco. However, unlike the other Taiwan-based ICT device firms, which rely much on offshore production, HTC maintains a world-class high-volume manufacturing facility in Taiwan.

Another factor that differentiates HTC from most of its peers in Taiwan is branding. In 2006 HTC started to promote its own brand. For this, among many other things, HTC has been engaged in transforming its innovation culture and capabilities from "design to order" with efficiency to value creation based jointly on cutting-edge technologies, creativity, software intelligence and services. Apart from its partnership with leading Western mobile operators, HTC intends to eventually become a household name alongside Apple and Nokia.

To achieve this aim, HTC was the first handset-maker to launch smartphones powered by Android, the open-source operating system (OS) developed by Google. In doing so, the company has developed a new operating system based on Google's Android OS. In addition, in collaboration with China mobile, HTC will launch some smartphones that support China Mobile's TD-SCDMA (Time-Division Synchronous Code Division Multiple Access) standard, and even to co-work with the Chinese operator to promote TD-LTE (TD Long Term

Evolution; 4G). For HTC, all of these efforts amount to a strategic attempt to establish new competencies and competitive advantages in order to withstand shrinking margins in the handset industry and its Chinese rivals' flocking-in with cost advantages.

2.2.4 Quanta

Table 11: Basic Profile of Quanta

Year of Foundation and operations	1988; "Quanta R&D Complex" (QRDC) in Taiwan as the global headquarters and offshore operation centers across Asia, America, and Europe
Main Products	OEM/ODM for notebook, PCs, smart phones, servers, digital TV, and automobile modules
Employees (2007)	Over 30,000
Sales (2008)	US$24,120.58 million
R&D (2008)	US$171.26 million
R&D/Sales (2008)	0.71%

Source: Compiled by CIER.

Equipped with its well-established ODM capabilities and business model, Quanta Computer, founded in 1988, has been the largest and specialised notebook computer producer in the world for a decade. For this, Quanta has established operation centres across Asia, America, and Europe to manufacture, configure, and service products as well as provide logistics supports to deliver products and services in a competitive and efficient way in the world. It is estimated that Quanta's world-wide market share of laptop computers had increased from 10% in 1990 to the peak of 30% in 2005, and then down to 22.5% in 2009. However, since its profit margin had fallen steadily from 12.7% in 2001 to 3.68% in 2007, Quanta is seeking for diversification. To keep competitive, Quanta is looking to cloud computing as a fertile ground for future development and services as an important source of value creation.

Quanta's journey of diversification started from 2002, when the company expanded beyond the razor-thin-margin notebook computer market and into then a higher-margin market segment of displays, giving birth to Quanta Display as a TFT-LCD maker. In 2005, Quanta won the right to build an ultra-low-cost machine for One Laptop per Child (OLPC), a U.S. non-profit program launched by Nicholas Negroponte of the Media Lab at the Massachusetts Institute of Technology (MIT). This kind of laptop costs no more than US$100, which is about one-fifth the price of even the cheapest notebook computers on the market. The aim of OLPC is to sell these machines to millions of students and others in the developing world. Though Quanta eventually managed to meet the target of mini-notebook computers, Eee PC launched by Asustek eventually becomes more popular and profitable. Right now Quanta has extended its businesses into enterprise network systems, home entertainment, mobile communication, automotive electronics and digital home markets. As a result of its efforts of diversification, 30% of Quanta's revenue comes from other products than notebook computers in 2009, with an aim to reach a 50-50 ratio in the future.

Quanta has been recognised by the Fortune magazine as one of the Global Fortune 500 Enterprises. Underlying this achievement as well as some others is the company's commitment to R&D. Quanta has over 30,000 employees worldwide of which more than 3,500 people are working in R&D and engineering development. In particular, Quanta Research Institute (QRI) was inaugurated in 2005, comprising advance R&D, corporate R&D, and business unit R&D functions within "Quanta R&D Complex" (QRDC), its global headquarters, near Taipei.

To ensure Quanta's long-term prospect with technological leadership, QRI has collaborated with leading institutions around the globe in a few cutting-edge research fields, including high performance computing algorithm, large bandwidth mobile communications, and more intuitive human interface. Working with the likes of MIT, National Taiwan University, Computing Center of Academia Sinica, and National Center for High-Performance Computing, QRI has tried to outreach to the external sources of state-of-the-art technologies. In particular, QRI alone devotes NT$$200 million in a project with MIT Computer Science and Artificial Intelligence Laboratory (CSAIL) in developing the next-generation computing and communication platforms. In 2009, Quanta also forms an alliance with the University of California at Berkeley to explore medical technology and cloud computing. In addition, part of Quanta's R&D internationalisation involves technical supports for production, minor improvements and debugging functions in Shanghai Manufacture City in China.

Based on its existing ODM advantages, Quanta is trying to mobilise its resources to implement a new type of Total Solution, called "SSDMM" (System Solution Design and Manufacturing Move) strategy. This SSDMM calls for an integration of downstream business offerings, including end-product solutions in the automobile, wireless (smart phones and third-generation handsets), entertainment (LCD TVs and consumer electronics products), enterprise (storage units and servers) and digital home sectors. As a result, Quanta is transforming itself from a manufacturer of notebook computers to a provider of a set of comprehensive total solution, termed "Service by Integration". Quanta intends eventually to progress further towards the direction of "Service by Innovation", with an aim to create value and profits with services. Barry Lam, the Chairman of Quanta emphasises that the company intends to "pursue the goal of "me first, me only", going beyond vertical disintegration or scale economies".

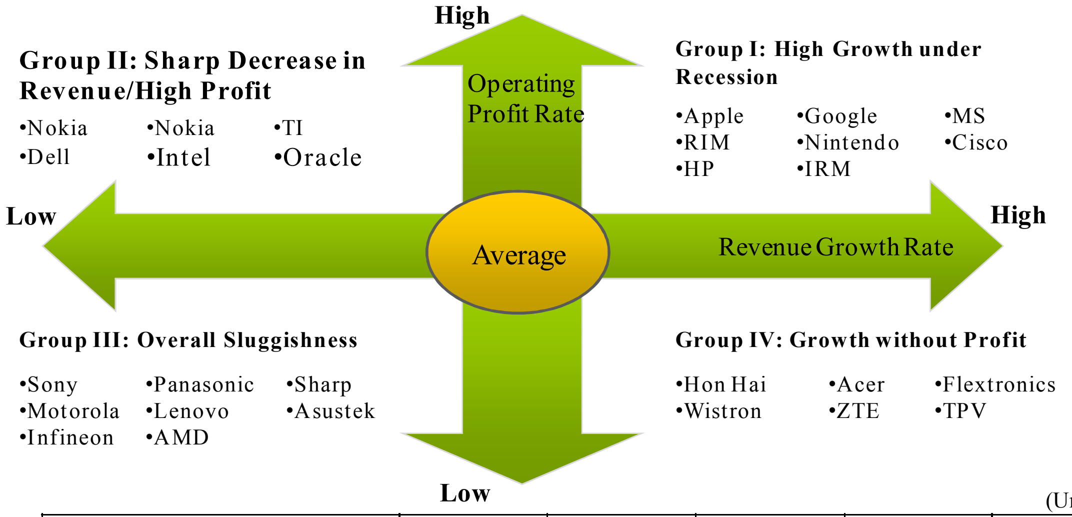
2.3 Micro-level assessment

In terms of micro-level assessment, we would like to start by referring to an analysis on earnings types for world's top 100 ICT firms, conducted by Samsung Economic Research Institute (SERI, 2009). In that analysis, the earnings of the world's top 100 ICT companies are categorised into four groups based on average revenue growth rates and operating profit rates. Group I, with both rates exceeding the average, accounted for 35% of all companies, while group III, with both rates below the average, accounted for 42% (see Graph 13). In addition, changes in earnings types for 2001 and 2008 for major ICT firms are also discussed (see Graph 14).

According to that analysis, some global leading players, such as Apple, Research In Motion, Nintendo, Microsoft, Google and IBM, tend to enjoy high operating profit rate, and even grow fast in revenues. In contrast, major Taiwanese ICT firms, such as Hon Hai, Acer, Wistron mostly fall into Group IV, with a high revenue growth rate and a low operating profit rate because "their profits substantially deteriorated due to a drop in product prices" (see Graph 13). The SERI analysis also reports changes in earnings types for 2001 and 2008 for some of the major ICT firms (see Graph 14). As far as Taiwan is concerned, IBM and HP, which were both previously in Group II, also moved up to Group I on the back of stronger competitiveness. In contrast, along with Sony, Hon Hai and Asustek, which were previously in Group I, moved down to either Group III or Group IV, suggesting a deteriorating growth rate of operating profits, and even revenues.

Indeed, Chen, Liu and Lin (2005) has documented that Taiwan's ICT industry, the computing/communications manufacturing subsector in particular, has faced an era of "razor-thin profit", bringing about such bottlenecks as growth of value added at a slow pace, deteriorating value added rates, and a decrease in the industrial linkage effect. These bottlenecks can only be fully comprehended by taking into account a wide variety of factors, including both the negative (for example a trend of sharp decline in price of the ICT products, international outsourcing and international division of labour within the GPN, large-scale capital investments and its locked-in effect in technological trajectory) and positive ones (for example, industrial upgrading leading to a rising dependence on foreign key components and equipment). To some extent, as the proverb goes, Taiwan can be the victim of its own success.

Graph 13: Earnings Types for World's Top 100 ICT Firms in 2008

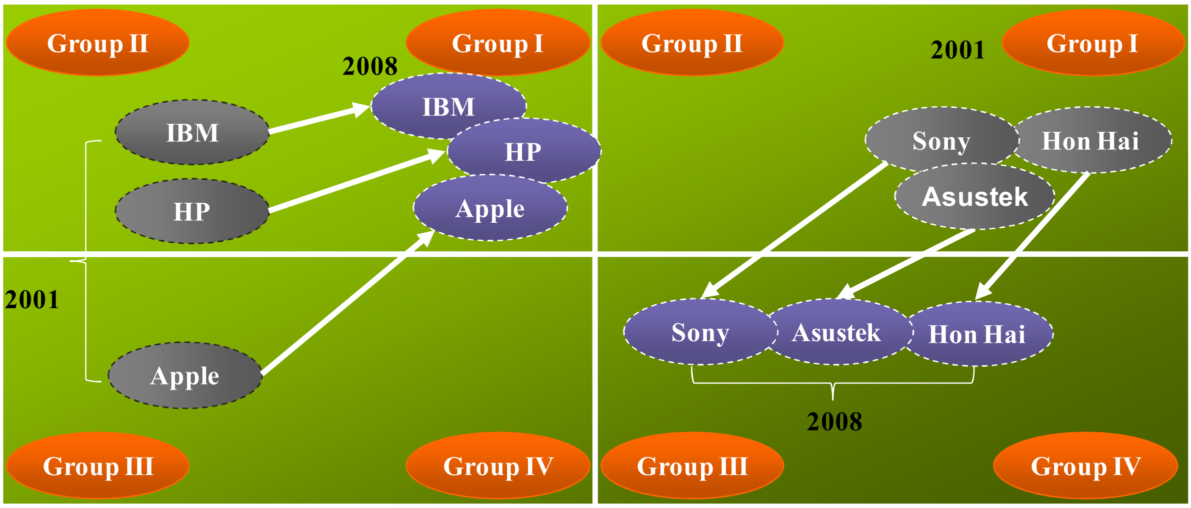


(Unit: %)

	Group I	Group II	Group III	Group IV	Total
Weight	35	11	42	12	100
Average Revenue Growth Rate	15.9	-5.8	-12.9	14.4	1.1
Average Operating Profit Rate	16.3	14.5	-2.7	-8.9	5.2

Source: Samsung Economic Research Institute (2009), accessed on 30, April, 2009. http://www.seriworld.org/03/wldKetV.html?mn=E&mncd=0302&key=db20090427003&sectno=3.

Graph 14: Changes in Earnings Types for 2001 and 2008 for Major ICT Firms



Source: Samsung Economic Research Institute, accessed on 30, April, 2009.
http://www.seriworld.org/03/wldKetV.html?mn=E&mncd=0302&key=db20090427003&sectno=3

Nonetheless, the Taiwanese ICT players are not without R&D and innovations, and are strengthening their value creation, particularly with growing emphasis on the incorporation of intangible goods and valuable services into their business models. Apart from the cases presented above, there are still some other cases demonstrating different profiles of the Taiwanese ICT firms from their previous stereotypes. For example, Acer's unique Channel Business Model has been instrumental in the company's latest success, trying to overtake Dell to become the second-largest computer brand in the world. The model encourages partners and suppliers to collaborate in a winning formula of supply-chain management, allowing Acer to provide customers with fresh technologies, competitive pricing, and quality service. Even Compal, an ODM vendor has positioned itself to know the end customers better than do its counterparts of brand marketers in order to better serve the latter and get itself closer to the end market. Hon Hai, apart from diversification into automotive electronics and green technologies, is also deploying channels within China in collaboration with German Metro Group in order to access the end market and exploit the booming domestic market in China.

CHAPTER 3. ICT R&D STRATEGIES

3.1. The Role of FDI in ICT R&D Trends

Taiwan's economic take-off benefitted to quite an extent from foreign direct investment, but since the mid-1980s Taiwanese firms have gone international via outward investment. As shown in Graph 15, from 1990s onwards, Taiwan's outward investment has in general outgrown its inward investment. In other words, since the late 1980s, Taiwan has been in the process of increasingly integrated with other countries in the region, initially those in Southeast Asia in particularly, and more recently China. Before 1986 Taiwan's international economic relations were connected mainly with Japan and the United States. Japan's technologies, machines, and key parts were imported to Taiwan to produce goods, and from its home base Taiwan exported to the United States and, to a lesser degree, Europe. After 1986 Taiwan's outward investment started to take off, initially to Southeast Asia and more recently to China. Indeed, from 1990s onwards, China has overtaken the Southeast Asian countries as the biggest host country for Taiwan's outward investment, with China's share of Taiwan's outward investment reaching 60-70% in the second half of 2000s (see Graph 16). Taking 2008 as an example, Taiwan's approved outward investment amounted approximately to US$15.16 billion, with 70.53% (US$10.69 billion) being directed to China.

In addition, Taiwan's FDI in China (as well as Southeast Asia) was pioneered by its labour-intensive sectors, and followed by the technology-intensive industries since the late 1980s. As a result, the geographical deployment of Taiwan-based firms has shifted from Southern China (the Pearl River Delta) to Eastern China (the Yangtze River Delta), and more recently to the Beijing-Tianjin-Hebei (BTH) Region, and even to the inland cities of Chongqing and Chengdu.[18] The availability of capable local engineers, cost effective local engineers, as well as linguistic and geographical proximities have attracted Taiwanese ICT companies to establish production sites and even R&D units in China. Of note is the fact that despite a growing strength of China's domestic demand, the Taiwanese subsidiaries' operations there used to mostly serve the international end market (Chen and Chen, 1998; Makino, Lau and Yeh, 2002), only recently have become local market-oriented.

Indeed, referring to Graph 17, both Electronic Parts and Components Manufacturing and Computers, Electronic and Optical Products Manufacturing, which are mainly ICT-related have recently accounted for more than 40% of Taiwan's annual outward manufacturing investment to China. As a result, China has become an important offshore production site for Taiwan-based PC and notebook computer firms, having significantly outweighed the latter's domestic production since 2002. Along with this development, not only has China's coverage of the ICT value chain at the mass production level become more comprehensive, but China is playing an increasingly important role in the ICT global innovation network, resulting in part from the relocation of Taiwan-based ICT firms' R&D functions (Chen, 2004; Ernst, 2006).

As discussed earlier in Introduction Section, FDI played an important role in triggering the initial development of the Taiwanese ICT industry in the early 1980s. Later onwards, the local firms, Acer and Tatung for example, were able to take up the vacuum caused by the withdrawal of the foreign firms during the mid-1980s, which then laid the foundation for the formation of the local industrial clusters.

[18] In this few years, Taiwanese ICT firms are driven by HP's and Dell's investment decisions to relocate part of their notebook computer production plants to Chongqing and Chengdu.

Since then, the local players, in many cases backed up by government R&D initiatives have steadily become partners to international brand marketers. As a result, even though the electronic and electrical field has been the major area of FDI to Taiwan for decades, MNCs operations in Taiwan have shifted towards international procurement offices and suppliers of key components and materials (for example, electronic chemicals) for local ICT manufacturing. With regard to manufacturing, FDI's supports to the local sectors have moved from to the PC and notebook computer subsectors, more recently to the IC and LCD subsectors. In particular, both the USA and Japan have been important sources of key components and parts, and manufacturing equipment for local ICT manufacturing. Even for IC design, the local industrial clustering has also lured other foreign networked firms, such as EDA tool providers to set up operations in Taiwan.

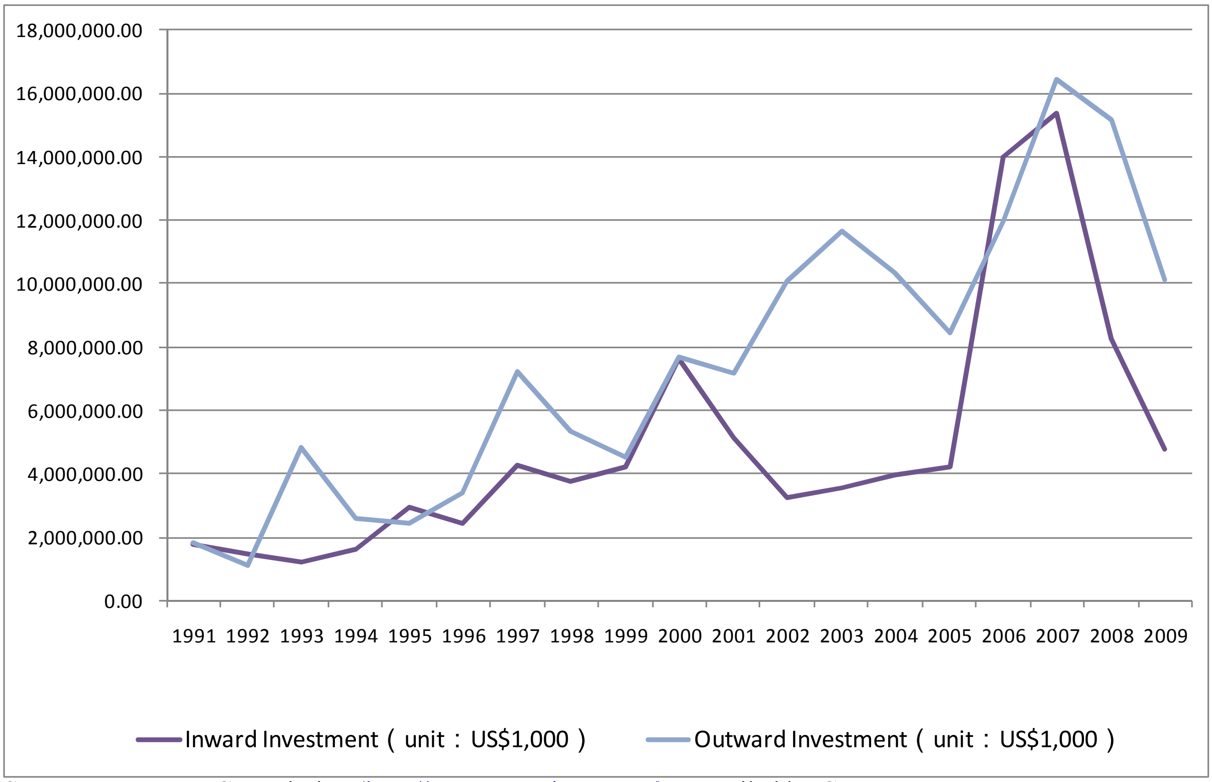
Apart from FDI in production, some of the MNCs in Taiwan have also invested in R&D. From the dataset provided by the Investment Commission of the Ministry of Economic Affairs (MOEA), Liu and Chen's (2005) calculations show that R&D intensity (R&D/sales) for foreign-owned subsidiaries in Taiwan's manufacturing sector increased from 1.52% in 2002 to 1.94% in 2003; which perhaps indicates that Taiwan's mandate has significantly improved in terms of MNCs' regional or GINs.

Liu and Chen (2005) have also managed to characterise, with statistical robustness, those foreign R&D subsidiaries with a higher R&D intensity in Taiwan. Among other findings, they found that those foreign-owned firms in Taiwan with a higher export propensity tended to be more R&D intensive, especially those of branding ICT firms. As an economy featured by international competitiveness and export orientation, Taiwan may be able to act as a host for some MNCs in order to capitalise on its comparative advantages to serve the international market.

Foreign-owned subsidiaries with higher R&D intensity are also found to be characterised by a greater degree of localisation in terms of their sourcing of both production materials and capital goods. This is particularly true for ICT brand marketers, which have relied substantially on local sourcing in Taiwan.

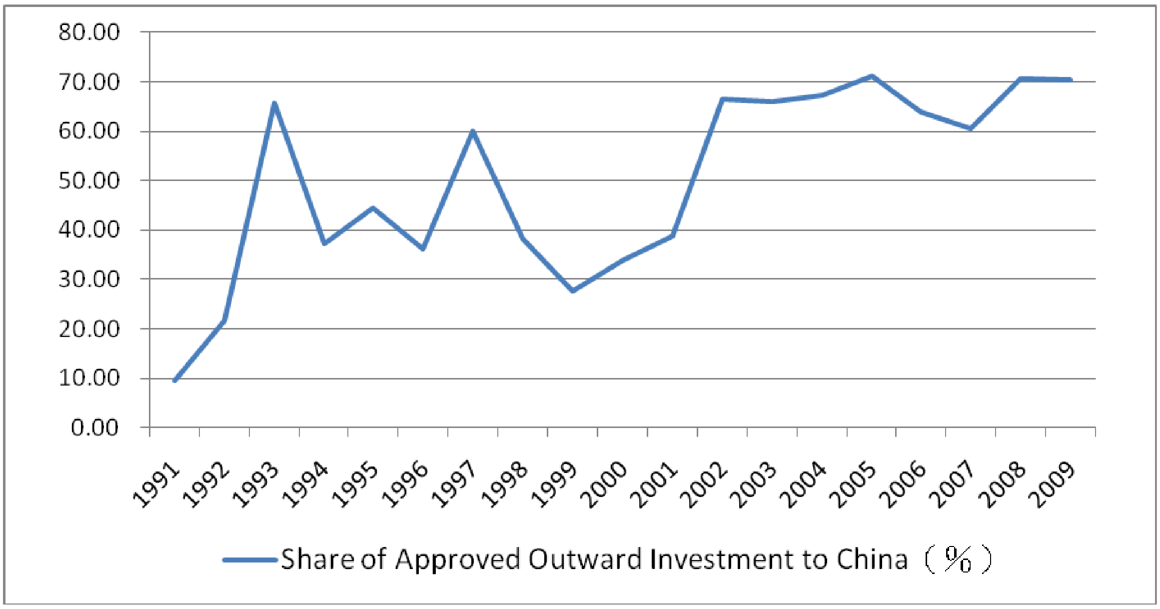
In addition, where Taiwan's industrial sectors have a larger pool of R&D employees, their constituent foreign affiliates tend be more R&D intensive. On the one hand, this seems to imply that the R&D efforts of foreign affiliates in Taiwan are driven by a local technology pool. On the other hand, assuming that a larger pool of R&D employees in a sector implies that its local firms are more technology aggressive, one can argue that indigenous R&D efforts serve as a complement to, rather than a substitute for, the R&D activities of foreign affiliates.

Graph 15: The Trend of Taiwan's Approved Inward and Outward Investment



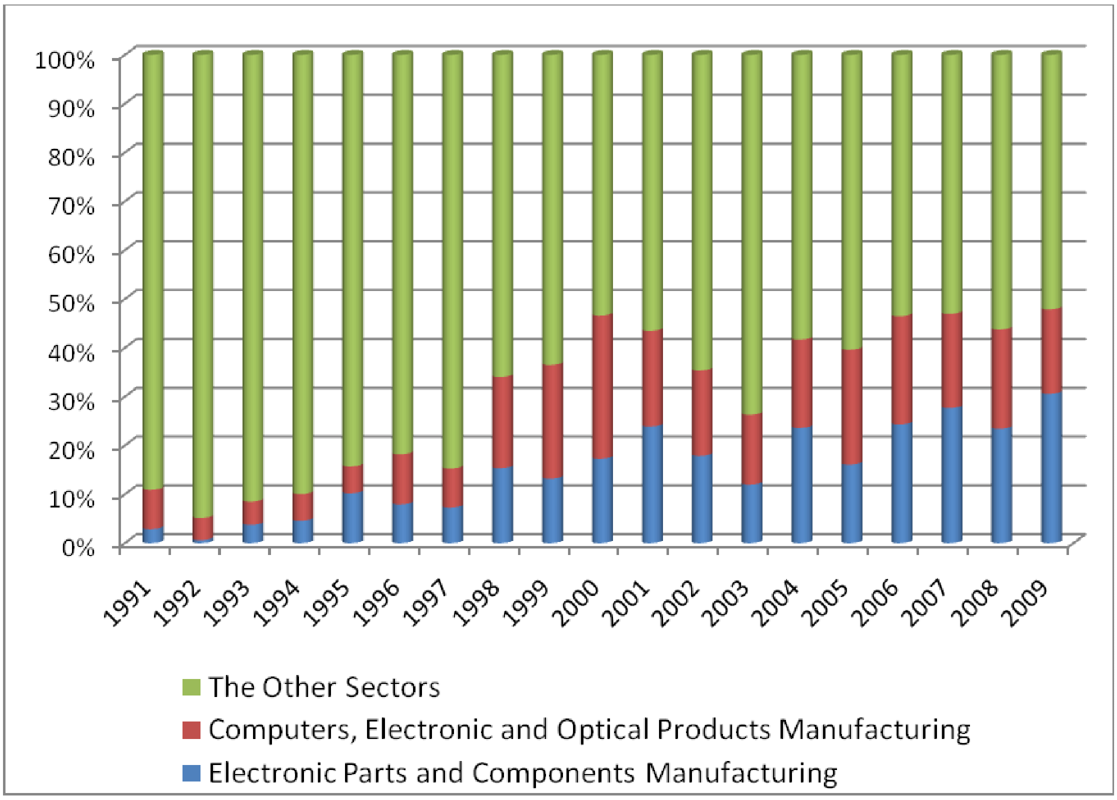
Source: Investment Commission (http://www.moeaic.gov.tw/); compiled by CIER.

Graph 16: The Share of Taiwan's Approved Outward investment to China



Source: Investment Commission (http://www.moeaic.gov.tw/); compiled by CIER.

Graph 17: Share of Approved Manufacturing Outward Investment to China, by Sector



Source: Investment Commission (http://www.moeaic.gov.tw/); compiled by CIER.

More than that, the government in Taiwan has orchestrated a plan to encourage MNCs[19] to establish R&D centres on the island, which since its implementation in 2002 has met with some success. Up to September 2010, sponsored by that programs there are so far some 46 R&D centres, established by 34 different MNCs. Of note is the fact that these R&D centers are related mainly to the current strength of Taiwan's industrial development, with the lion's share (65%) being focused on the broadly defined ICT area and showing a strong intention of collaborating with the local firms. This may have something to do with the position of Taiwan's ICT industry within the global production and innovation network. In the case of the HP, IBM, and Motorola, the major players in Taiwan's ICT industry can be regarded as these companies' first-tier suppliers and/or ODM partners, especially with regard to components and barebones. As brand marketers have become hollowing out, collaborative research and design between the brand marketers and first-tier suppliers have increasingly come to the fore, which may be facilitated by the geographical proximity between the two parties' knowledge bases. As for the Microsoft Technology Centre, Microsoft provides essential platform technologies to the local ICT industry, based on which the latter may develop new products for the international as well as domestic markets. However, the role played by the offshore R&D facilities in this case has gone beyond the traditional technology transfer units, which tend to perform adaptive R&D to meet local needs, but is by nature in line with the prevailing collaborative research and design model. In fact, some of their intelligent property outputs have been adopted by the R&D headquarters (Chen, Chen and Wen, 2009).

[19] Four cases of MNCs' R&D will be presented in Section 3.2.2, with comparisons between Taiwan and China.

Such innovation offshoring is different from the familiar notion of R&D internationalisation which tends to take a position that individual MNCs are the unit of analysis. Regarding the latter, MNCs' offshore R&D is perceived as part of their own international R&D networks, facilitating them to exploit or explore both internal and external resources. However, our version of R&D internationalisation has something to do with the current restructuring in the ICT sector on the global scale. Within this process, different layers of industrial players are increasingly required to closely interact with one another for innovation. As part of this restructuring, this externalisation of innovation no longer stops at the national border, involving the reconfiguration of MNCs' international R&D networks (Chen, 2007).

3.2. Asian R&D Offshoring

3.2.1 R&D Offshoring in China by Taiwan-based ICT Firms

Taiwan has been among the top FDI investors in China and the Taiwanese investment there has gone beyond manufacturing activities, increasingly involving the R&D function (Chen, 2004; Liu and Chen, 2007). This trend coincides with the surge of China as a hotspot for MNCs' offshore R&D in the developing world[20] (Gassmann and Han, 2004; National Science Foundation, 2005; Chen et al., 2009; Han, 2006; Reddy, 2000; Walsh, 2003; UNCTAD, 2005) and China's widely-publicised attempt to promote indigenous innovations, more recently (Sigurdson, 2005). Compared to those from the developed countries, Taiwan-based MNCs' R&D activities are less globalised. Their offshore R&D is related mainly to overseas production (Liu and Chen, 2007).

Taiwan's FDI in China was pioneered by its labour-intensive sectors in the late 1970s, and followed by the technology-intensive industries since the late 1980s. As a result, the geographical deployment of Taiwan-based firms has shifted from Southern China (the Pearl River Delta) to Eastern China (the Yangtze River Delta), and more recently to the Beijing-Tianjin-Hebei Region. In addition, the availability of capable local engineers, cost effective local engineers, as well as linguistic and geographical proximities have attracted Taiwanese ICT companies to establish R&D units in China. Access to engineers, proximity to manufacturing site, and competition avoidance are considered as the major location decision factors. Of note is the fact that despite a rising strength of China's domestic demand, the Taiwanese subsidiaries' operations there used to mostly serve the international end market (Chen and Chen, 1998; Makino, Lau and Yeh, 2002), only recently have become local market-oriented.

Indeed, in recent years, the electronics and electrical appliances industry, which is mainly ICT-related has accounted for approximately 40% of Taiwan's annual outward investment to China. As a result, China has become an overwhelmingly important offshore production site for Taiwan-based PC and notebook computer firms. Along with this development, not only has China's coverage of the ICT value chain at the mass production level become more comprehensive, but China is playing an increasingly important role in the ICT GIN, resulting in part from the relocation of Taiwan-based ICT firms' R&D functions (Chen, 2004; Ernst, 2006).

In a previous study, a questionnaire survey was undertaken to examine the extent to which Taiwan-based ICT firms were engaged in R&D in China (Chen, 2004). The results showed that 47.56% of respondents had conducted R&D activities in China, implying that China had

[20] According to incomplete statistics compiled by China's Ministry of Commerce, as of the end of 2010, China has more than 1,200 R&D centres set up by multinational companies. (http://www.whatsonxiamen.com/invest473.html)

become the major target for these Taiwanese ICT firms' offshore R&D in quantitative, though not necessarily qualitative terms.

Based on information obtained from the structured interviews, Chen (2004) has also identified five types of R&D portfolios across the Taiwan Strait. First of all, where Taiwan-based firms' production lines are concentrated in China as well as other countries, product development is undertaken in Taiwan, whilst engineering support and manufacturing-related R&D is undertaken in China. This seems to be the major type and often entails the de-linking of R&D and manufacturing in terms of location. Secondly, some Taiwanese ICT firms outsource their software development services (for example Inventec) from China partly because of the leapfrogging potential of software. The third type of portfolio involves a tendency for some Taiwanese firms to perform their basic research in China (for example Hon Hai), which often involves collaboration with local universities and/or research institutes. The fourth type has some Taiwanese firms performing their upstream (core) R&D (or R&D for products at the developmental stage) within Taiwan, whilst their subsidiaries in China carry out downstream (non-core) R&D (or R&D for products at the mature stage). Finally, there are also cases where Taiwanese firms perform R&D in China for systems-related products, often modular products for the local market, such as motherboards for communications systems, whilst performing R&D for peripherals, such as handset motherboards, in Taiwan (see Table 12).

In fact, GPNs in the ICT industry have come to resemble a 'just-in-time' system on a global scale which entails the modularisation of production across different sites and borders (Chen and Liu, 2003). As a result, concurrent development tends to become the norm in the industry for the introduction of new products into the marketplace, and this can be facilitated by the application of information and communication technologies. In light of this, it is not surprising to see that the Taiwan-based ICT firms have, to a large extent, mandated their Chinese subsidiaries to undertake certain elements of their R&D. As argued by Ernst (2006: 14), "competitive success critically depends on vertical specialisation. Global firms selectively outsource certain capabilities from specialised suppliers and they offshore them to new, low-cost locations". This situation applies to not only the brand marketers but also their Taiwanese OEM/ODM counterparts.

Table 12: Cross-Strait R&D Deployment by Taiwan-based ICT Firms

		Taiwan	China
Product	Type	Peripherals	System-related
	Market	International market	Domestic market
	Life Cycle	Development stage	Mature stage
Attributes of R&D or Technology	Software & Hardware	Hardware	Software
	R&D Process	Product & process R&D	Basic research、verification and fine-tuning of process

Source: Adapted from Chen (2004).

As discussed in Introduction Section, to facilitate the innovation network between Taiwan's ICT firms and their network flagship counterparts, the Taiwanese government has since 2001 sponsored a series of Benchmark Project of e-Business in the ICT industry, also known as Plan A, B, C, D, E and G. The scope of these plans includes promoting electronic payments, e-financing and capital management for cash flows, delivery tracing management and transportation planning for delivery flows, and simultaneous R&D, design changes and information sharing for collaboration. As a result, the Taiwanese ICT firms together with their global partners are involved in not only inter-organisational coordination of the supply chain but also cooperation in product definition, design, and R&D. In this way, inter-organisational and cross-border production networks in the "bricks and mortar" world are transformed into virtual supply networks and collaborative communities (Chen, 2002).

However, one should not jump to the conclusion that the Taiwan-based ICT firms only look to China for R&D offshoring. In fact, the advanced countries are still important to the outward R&D internationalisation of Taiwanese ICT industry. To give an example, Delta, a technology-based supplier of power supply systems, has woven an extensive international network of 23 R&D engineering labs, with nearly half of them being located in the USA and Europe. The existing evidence even reveals that Taiwanese firms' offshore R&D in the advanced countries shown a strong feature of "technology augmentation" (technology sourcing, in other terms), while that in the developing country tends to focus on "technology exploitation" (Liu and Chen, 2007).

3.2.2 MNCs' R&D Offshoring in Taiwan and China

Since the 1990s, MNCs' overseas R&D has also been expanded to the developing world. In particular, such countries as India (Reddy, 2000) and China (Xue and Wang, 2001; Chen et al., 2009; Gassmann and Han, 2004; Walsh, 2003; UNCTAD, 2005) have been documented as high-profile host countries for MNCs' offshore R&D facilities (UNCTAD, 2005). More importantly, the existing evidence (Chen et al., 2009) tends to suggest that MNCs' offshore R&D mandates have increasingly gone beyond the traditional pattern of technology transfer and adaptive R&D in developing host countries (for details, see the reports of the Chinese and Indian Teams).

More importantly, the emergence of China is, in some aspects, characterised by leapfrogging, which may entail a structural shift of innovation across the Taiwan Strait. Christensen, Craig, and Hart have argued that such countries as China and India may bring about "the great disruption" and that "technologies emerging from these countries (China and India) may have profound but unpredictable implications for the rich world's markets." This seems to suggest that new patterns and flavours have surged from the current trend towards R&D globalisation, including R&D offshoring, technology sourcing, offshore collaboration, particularly regarding developing host countries. In this way, MNCs' offshore R&D mandates have increasingly gone beyond the traditional pattern of technology transfer and adaptive R&D in developing host countries. Both R&D offshoring and technology sourcing often involve software, basic research, and even new market insights. However, from the perspective of the host country, this may lead to the possibility of "enclave," due to limited local linkages. Offshore collaboration, on the other hand, tends to take the form of inter-organisational, cross-border collaboration for innovation, facilitated by modularisation of product (see Table 13).

It follows that certain rules of the game for R&D and innovation may have begun to change, at least in relative terms. First of all, certain types of R&D internationalisation may involve de-linking of R&D and manufacturing/commercialisation in terms of location, unlike the case of technology transfer and adaptive R&D. Such a situation implies that MNCs' offshore R&D may not necessarily lead to the creation of a new industrial segment for the host country, hence generating limited spillover effects. Secondly, some of developing countries have increasingly become a source of R&D and innovation, not just a technology recipient and late-adopter. Following this, players in the developing world may serve as a partner of collective innovation, with their involvement at the early stage of the product life cycle.

Table 13: Two Sides of the Coin for MNCs' Offshore R&D

Pattern	Conditions required in the host countries
R&D offshoring and technology sourcing	■ Cost/technology-driven □ Abundant supply of R&D workers □ Strong science base & achievements ■ Market/application-driven □ Sheer size of market potentials □ Lead market, demanding needs as an innovation trigger □ Right conditions as a test-bed
Offshore collaboration	□ Specialised and accumulated capabilities for commercialisation of innovation □ Complementary assets for innovation in terms of industrial ecology

Source: Adapted from Chen (2007).

Drawn upon our previous studies (Chen et al., 2009), the following presents R&D cases of four major MNCs in the ICT industry in both China and Taiwan: Motorola, Microsoft, IBM, and Hewlett-Packard (HP).

Motorola

Motorola is a global major player in mobile communications. With its R&D headquarters in Schaumburg in Illinois, Motorola began to disperse its R&D to some of the advanced countries in West Europe before the 1980s. After that, the company further extended its global R&D network to the second layer, located in such countries as India, Israel, Ireland, and Canada, and more recently to East Asia because of the rising capabilities in mobile communications in the region.

Since its first entry into China in 1987, Motorola has grown into the largest foreign investor in terms of not only capital formation but also R&D investment. Motorola set up its first R&D center in China--Global Software Group China Center - which coincidentally is also China's first multinational R&D center. In addition, Motorola China Research and Development Institute (hereafter Motorola Institute) was established in Beijing in 1999, demonstrating Motorola's commitment to R&D and collaboration with technology partners in China. Right now Motorola Institute has grown into the biggest multinational R&D institute in China with over 1,500 R&D staff and 15 R&D centers, ranging from research labs, global software groups to development centers, in such major cities as Beijing, Tianjin, Shanghai, and Nanjing. In particular, the software capability of Motorola Institute has been verified as "capability maturity model integration" (CMMI) level five. Motorola Institute was established to capitalise on China's booming domestic market and rich talent pool. According to a high-ranking official in Motorola China Research Lab, about 87% of their R&D expenditures are related to software. In addition, Motorola Institute has formed complex external R&D networks, in collaboration with not only China's major industrial players but also some of its leading universities.

In response to the Taiwanese government's initiative, Motorola set up a Motorola Taiwan Product Development Center in 2004. This was also related to the company's role as a leading procurer in Taiwan for mobile devices. As a result, the center's mandate concerns mobile devices, working on such areas as handsets, semiconductors, and the energy system, in which the Taiwanese suppliers have competitive advantages. In essence, Motorola Taiwan Product Development Center functions as a bridge for the company to work closely with its major original design manufacturing partners in Taiwan by providing a reference platform for mobile devices and assisting in the development of new products in a time-to-market manner.

Microsoft

Microsoft has set up five research labs around the globe, mainly in the US (Redman, San Francisco, Mountain View) and the UK (Cambridge). The Microsoft Research Lab in Beijing was established in 1998, and it is now called Microsoft Research Asia. It conducts basic research in a number of fields, being the company's first research lab in the developing world and acting as Microsoft's regional research center in Asia. In addition, Microsoft Research India was established in Bangalore in January 2005, and is mandated to conduct cutting edge basic and applied research in multiple fields in computing, information technology, and related areas.

Microsoft Research Asia is Microsoft's fundamental research arm in Asia Pacific, conducting fundamental curiosity-driven research related to Microsoft's long-term vision and strategy. Its research agenda covers a few areas, including a next-generation user interface, next-generation multimedia technologies, digital entertainment, wireless and ubiquitous networking technologies, and web search and data mining. Microsoft Research Asia has grown into an accomplished research lab with more than 180 researchers and an output of over 1,200 published papers. Since 1998, Microsoft Research Asia has developed extensive university relations in China and in the region, examples of which include theme-based projects, joint research labs, joint research funding, and Chinese government-accredited postdoctoral stations.

In addition, in 2005, Microsoft Research Asia and MSN Search have teamed up to create a Search Technology Center in Beijing. The center is dedicated to "advancing the state-of-the-art in search technology and delivering a more intelligent and powerful search experience to MSN users around the world." One of its missions is to accelerate innovations by seamlessly combining research and development in Microsoft Research Asia, bridging fundamental research and product development.

Apart from the research labs, Microsoft also deploys a global network of technology centers. They are located mainly in the US, the UK, Germany, and Japan. The Microsoft Technology Center in Taiwan has been recently established in response to the government's initiatives. By providing the company's XML web service and .Net technologies, the Microsoft Technology Center aims to assist in advancing the software (mainly embedded) development industry in Taiwan, via joint business development and engagement, and to provide a portal for academia and business to combine skills and knowledge. To achieve these aims, the center - supported by the company's technology centers in the US and Europe - has teamed up with not only independent software vendors but also some local research institutes and universities. In particular, Microsoft has undertaken a high impact project which involves the Institute for Information Industry, a local research institute dedicated to the software and IT industries.

Though positioned as a technology transfer unit, out of its cooperation with local partners, the Microsoft Technology Center has generated some intelligent property outputs adopted by its headquarters. As a result, with support from headquarters, the Microsoft Technology Center has extended its mandates by establishing a Windows Media Engineering Center in order to facilitate the development of the digital home industry in Taiwan.

IBM

IBM has set up eight research labs around the globe, mainly in the developed countries, though two of them are located in China (Beijing) and India (New Delhi). In particular, the IBM China Research Lab is mandated to function as a watch port and to conduct exploratory research mainly on e-banking because of the sheer volume of e-banking in China. In addition, the company maintains some 27 product development centers worldwide. Those in Asia include Beijing and Shanghai in China, Yamato in Japan, Seoul in Korea, Taipei in Taiwan, and Bangalore in India.

Starting as a small R&D site, IBM China Research Lab has grown into IBM's global research network, now staffed by more than 200 researchers. Its research agenda focuses on software and global business service consulting, with a specific aim to conduct research centered around customers' needs. Alongside IBM China Research Lab, the company also set up a China Software Localization Center and an Industry Innovation Center in Beijing, with both of them focusing on the downstream and tailor-made part of the R&D process. IBM's R&D commitment in China has much to with the progress of the company's business relationship with China, which has evolved from "investment to learn," via "investment to grow in China," "towards investment to grow for China and leveraging China's strength." According to a senior staff member of IBM China Research Lab, China's strength lies mainly in its "unique workload with broad applicability," especially regarding services and e-commerce, which may enable IBM to develop new software, technologies, and services as the mainstream in the future or the first of its kind worldwide.

Motivated in part by the government's initiative, IBM has established the IBM xSeries Taiwan R&D Center. The center is mandated as the "mission lab" for IBM's low-end (xSeries) servers, the only server R&D center outside the US. The American R&D headquarters in Raleigh, together with R&D facilities in Kirkland and Austin, are in charge of high-end servers (pSeries, iSeries, and zSeries). As compared to a "job shop," a mission lab is positioned to shoulder the entire R&D process (ranging from the concept phase, planning phase, development phase, qualification phase, and launching phase to the life-cycle phase) for its product mandates. Hence, the IBM xSeries Taiwan R&D Center has been given the full support of its headquarters which sent a few senior experts from Raleigh on a long-term basis and the Taiwan R&D center has been given a mandate to set its own research agenda. Taiwan outcompeted China and India in terms of IBM's locational decision for the xSeries R&D Center mainly because of the local ICT industry's strengths in terms of product development and rapid response capability. Therefore, ever since day one, the IBM xSeries Taiwan R&D Center has been closely collaborating with the local IT industry, which is regarded as IBM's first-tier supplier. Their cooperation has taken the form of "collaborative design" and covers the whole process, ranging from the engineering sample, design valuation test, engineering valuation test, and production valuation test. Such collaboration, though existing for quite a long time, used to take place across the Pacific Ocean. By relocating the xSeries R&D center from Raleigh to Taipei, IBM, together with its suppliers in Taiwan, has managed to shorten the R&D cycle time from 7-11 months to 5-9 months. In addition, partly because of the center's positive outputs, IBM has equipped the center with product mandates for higher-end servers (pSeries and iSeries).

Hewlett-Packard (HP)

HP, a global leader in the ICT industry, has a global network of six research labs around the world, mainly in the developed world (Palo Alto in the US, Bristol in the UK, Tokyo in Japan, and Haifa in Israel), and two others located in Bangalore, India and Beijing, China. Initially, the company's research network was concentrated in the US and the UK, but it began to extend its reach to Japan in 1990, India in 2002, and China in 2005. The company's research lab in India is mandated to conduct research on ICT mainly for potential users in the developing world.

Established in 1985, HP China has become the company's largest subsidiary in the Asia Pacific region. In 2002 HP set up a software R&D center in Shanghai, which is now staffed by more than 200 software experts and is planned to scale up to 1,500 R&D personnel in the next few years. This R&D center serves two purposes: one is to be part of HP's global R&D network, and the other is to provide total solution to serve the local needs in China. In addition, HP Laboratories China was launched in November 2005, with a mandate "to strengthen the partnership between HP and China's premier research institutions and major industrial customers." As a result, HP Laboratories China has formed a number of R&D links with local universities and research institutes, supported by the Chinese Ministry of Education.

For years, HP has been the largest foreign procurer in Taiwan for ICT products made by the Taiwan-based firms. Thanks in part to this, HP's subsidiary, together with its major local suppliers in Taiwan, has been heavily involved in e-commerce initiatives sponsored by the government, ranging from online global logistics to online joint product development. In 2002, HP set up an HP Product Development Center in Taiwan, which was not only relocated from Singapore but also given a broader geographical mandate to serve the global market. In addition, the center serves to perform product development in four areas, including desktop computers, notebook computers, servers, and hand-held devices, in which the Taiwanese suppliers have well-established capabilities in original design manufacturing. According to its staff, the HP Product Development Center has come into existence for the following reasons: (1) proximity to suppliers; (2) access to supply side knowledge; and (3) to gain support for its development efforts.

Referring to the above-mentioned four cases of MNCs' ICT R&D on both sides of the Taiwan Strait, Chen et al. (2009) have drawn some interesting patterns of contrast between Taiwan and China, especially in relative terms, which is summarised in Table 14. First of all, in terms of the dimension of software vs. hardware, the MNCs' R&D centres in China tend to focus more on software, while their counterparts in Taiwan focus on hardware. In addition, in terms of their local R&D linkages, the MNCs' R&D centres in China show a strong tendency to forge linkages with the local research community, while their counterparts in Taiwan tend to collaborate with the local firms, their suppliers in particular. Above all, the four cases examined tend to suggest that the MNCs' R&D centres in Taiwan are all mandated as product development centers, while their counterparts in China tend to function as research labs, in a couple of cases along with product development centers.

Table 14: A Comparison of the Flagship MNCs' R&D between Taiwan and China

Dimensions	Focal point (In Relative Terms)	
	China	Taiwan
Software or hardware	Software	Hardware
Focus of R&D	Upstream R & technology	Downstream D
Local technology linkages	Higher Education Institutes	Local suppliers
Position within the parent's global R&D network	Research lab	Product development centre
Market targeted	Domestic market	International market
Scale by headcounts	Larger	Smaller

Source: Adapted from Chen, Chen and Wen (2009).

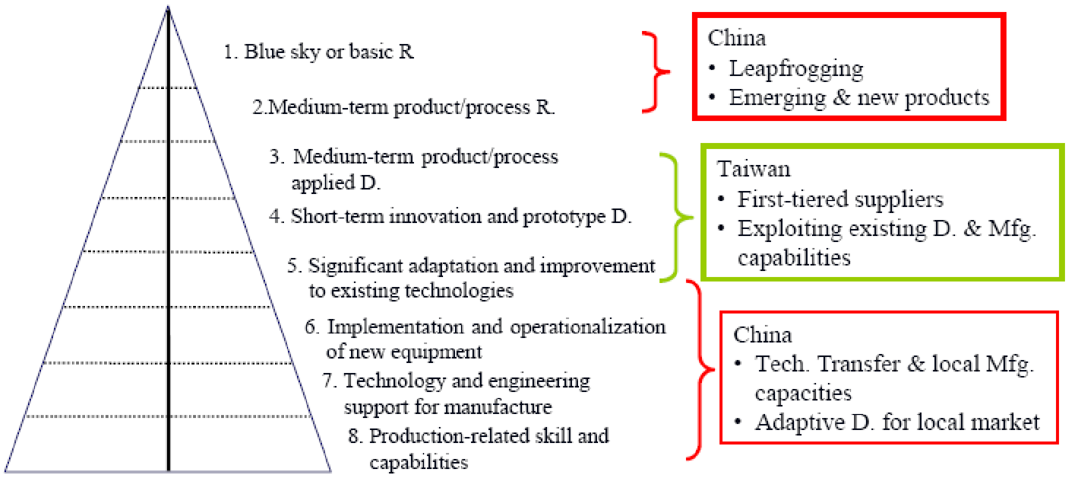
This may have something to do with the features of Taiwan's national innovation system (NIS) in terms of the ICT industry. From the perspective of the evolutionary approach to technology, what a firm and an economy can do, or is about to do, is linked strongly to their routines and previous bases. It can be argued that the mainstream of Taiwan's industrial technological innovation currently lies mainly in the central part of the smiling curve, which ranges from incremental technological changes to defensive and cost saving patents, as discussed below. In addition, it is generally perceived that the ICT community in Taiwan undertakes more "D" than "R." The MNCs may therefore feel more comfortable in capitalising on the strengths of Taiwan's national innovation system by establishing product development centres.

In contrast, while China is behind Taiwan on the ladder of economic development, there may exist in China the possibility of leapfrogging development, which may allow the firm or the country concerned to bypass certain stages of the technological trajectory, or jump straight into a new generation of technology. Apart from having a large pool of R&D personnel and market potential, China's science and technology system formerly placed relatively greater emphasis on basic research, partly because of the arms race during the Cold War period. In addition, China's economic development has come to the stage where some proportion of the Chinese population may be able to and also wish to consume state-of-the-art products. This may equip China with leapfrogging potential on the demand side. Therefore, it makes sense for some of the MNCs to set up research labs in China and to conduct more advanced R&D activities, although the bulk of foreign R&D in China may be related to adaptive R&D (see also Walsh, 2003; Chen, 2008).

Based upon these observations, Chen et al. (2009) even go further to put forward a holistic view of the possible R&D portfolio of flagship MNCs on both sides of the Taiwan Strait, as shown in Graph 18. In essence, based on the heritage of industrialisation in the ICT industry, Taiwan has been able to capitalise on its first-tier supplier advantage as a means of attracting a few MNCs to set up their offshore R&D facilities on the island. As a result, those MNCs have tended to conduct certain types of R&D in Taiwan, ranging from medium-term product/process applied development, short-term innovation, and prototype development to significant adaptation and improvement to existing technologies. By contrast, to quite an extent, while the bulk of foreign R&D in China may be related to adaptive R&D, some, if not many, of the MNCs are conducting strategic R&D in China, such as blue sky or basic research and medium-term product/process research (see Also Chen, 2008).

Some might hence get an impression that research conducted by the MNCs may mean more to the host country than development does. Such an impression can be oversimplified. Instead, Chen (2007) has argued that development conducted by the MNCs in Taiwan often entails close interactions with the indigenous firms, and hence could bring benefits to the local economy in an immediate and direct way. By contrast, with regard to research conducted by the MNCs in China, it has to take time, not to mention the risk involved, for results from the research to bear commercial fruit. However, where the research involves emerging technologies and/or industries, it is possible that R&D conducted in China can redefine the technological order across the Taiwan Strait, if not the world. This will become more likely if R&D conducted by MNCs in China eventually goes through the commercialization process by working together with China's indigenous value chain, giving rise to leapfrogging development in China.

Graph 18: Possible R&D Portfolio of Flagship MNCs across the Taiwan Strait



Source: Adapted from Chen, Chen and Wen (2009).

3.3. Core Skills in ICT R&D

Along with the trend towards Asian R&D offshoring discussed above, brand marketers are becoming increasingly linked to their first-tier suppliers in terms of innovation capabilities. Based on their indigenous capabilities accumulated through long-standing contract work for the brand marketers, the Taiwanese ICT firms are increasingly involved in the collaborative research and design process led by the brand marketers. Although the driving seat is occupied mainly by well-established firms in the advanced nations of the world, firms in countries such as Taiwan also have a role to play.

In fact, Taiwan has been very active in US patenting. In this regard, Taiwan has ranked fourth for eight years in a row (1999-2006), second only to the US, Japan and Germany. In addition, the electrical and electronic machinery, equipment and supplies sector as a product field outnumbers all other fields, registering an increase from 2,013 to 7,644 in the second half of the 1990s. Since then, the ICT-related fields have been the major part of Taiwanese patenting in the USA. For example, in 2008, three leading fields of Taiwanese US patenting include Active Solid-State Components (453 items), Semiconductor Manufacturing Devices (441 items), and Connectors (396 items). All these taken together may imply that Taiwan's industries, the ICT sector in particular, have moved from foreign technology to indigenous

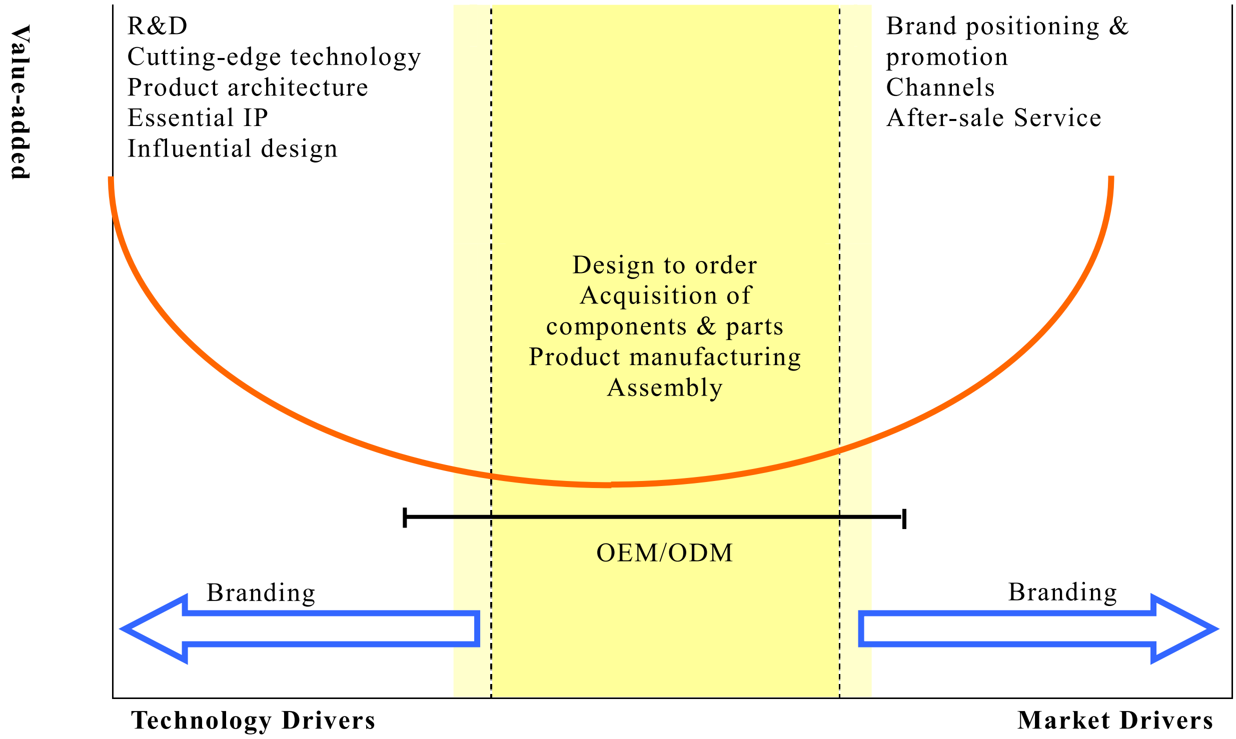
innovation (see also Wu, et al., 2002; see Chapter 4 for discussions on Taiwan's national innovation system).
In general, Taiwan's computing/communications manufacturing subsector has been featured by heavy reliance on OEM/ODM contract work for brand marketers. In terms of core skills in Taiwan's ICT R&D, this gives rise to an important question as to what kinds of competencies differentiate the Taiwanese ICT players from their branding counterparts. In our opinion, answers to the above question may be obtained by referring to "Smiling Curve", as shown in Graph 19 (Chen, Wen, Liu, and Lin, 2006).

The "Smiling Curve" (see Graph 16) first coined by Stain Shih, the founder of the Acer Group, has implied the possibility of variations in profitability among the constituent firms in an industry. The "Smiling Curve" suggests that in many industries profitability at various stages of the value chain has come to follow a U-shaped curve, high in the upstream and downstream processes but low in the midstream processes. In other words, the position a firm holds along the value chain will have a great impact on its profitability. More importantly, the points made by Teece (1986) regarding complementary assets suggest that the tasks that individual stages of the value chain contain may be closely related in terms of making an innovation pay off. However, the way to have all these tasks connected does not necessarily require complete internalisation within a (branding) firm, instead collaboration, licensing and even arm's-length transaction for certain tasks can be the alternative means to achieve this end.

Therefore, it could be oversimplified to argue that what differentiates Taiwanese OEM/ODM manufacturers from their customers, brand marketers, is about building up and/or getting access to capabilities on the right-handed (market driver) side of the Smiling Curve. Being an OEM/ODM manufacturer, a firm in question is obviously kept from the value chain on the right-handed side of the Smiling Curve. However, as suggested by the evolutionary approach to technology (Nelson and Winter, 1982), what a firm can do, or is about to do, is linked strongly to their routines and previous bases. In other words, the firm as an OEM/ODM manufacturer, no matter how innovative it is, may not be familiar with the rule of the game on the technology-driver side.

The ability to define and master product architecture and conduct system integration is probably another factor that differentiates branding firms from their OEM/ODM counterparts. Since a branding firm shoulders the role to communicate with and deliver promises to its customers, it is supposed to be able to define the product architecture. On the other hand, what an ODM manufacturer does typically is devote "their efforts on a specialised field of application or technology" (Hilmola, Helo and Holweg, 2005:7), or at most, packaging existing technologies and components in line with the product architecture defined. The success of iPod, which has reversed the fortune of Apple, can be considered as a typical example, demonstrating how great product architecture contributes to the resurgence of a brand. In fact, nearly all of the guts of iPod are made by others, but it is Apple that "integrates these discrete components (through software intelligence) and packages them in the clean white-and-chrome bathtub" (Conley, 2005: 3).

Graph 19: Capabilities and the Value Chain along the Smiling Curve

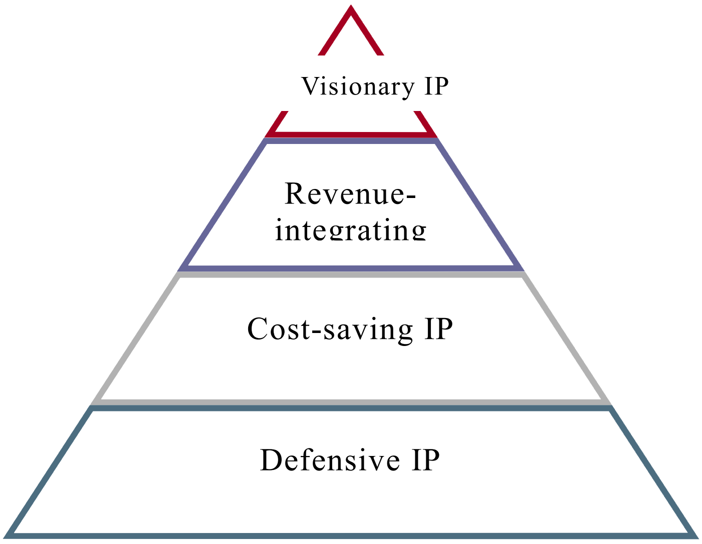


Source: Adapted from Chen, Wen, Liu, and Lin (2006).

Because of their being "locked-in" and their dependence on the pathway led by the architectural design created by leading brand marketers and industrial standard setters, R&D investment and innovation on the part of Taiwanese ICT firms in many cases takes the form of "customer engineering" and/or "design to order". In some cases, an ODM manufacturer even has to establish different R&D task forces, with few and even none interactions among them, to serve individual customers of brand marketers, rendering the duplication of R&D efforts on the part of the Taiwanese firms.

In relation with the R&D skill issue, these two kinds of firms also differ in intellectual property (IP). To discuss this issue, we would like to refer to a classification of IPs, proposed by TSMC (see Graph 20). According to TSMC, various kinds of IPs differ in their value, including defensive IPs, cost-saving IPs, revenue-integrating IPs, and visionary IPs. The first two kinds of IPs, sounding self-explanatory, tend to be lower in terms of their value to the owners and their impacts on industrial innovations. There are grounds to suggest that these are associated mainly with OEM/ODM manufacturers mostly because the latter, as argued above, tend to focus their R&D efforts on incremental technological change in relation to a specific technological trajectory and pursue technological innovation along the pathway led by the architectural design created by leading brand marketers. What's more, they are often required to shoulder the role of design for manufacturing and for volume.

Graph 20: A Classification of IPs by TSMC



Source: Adapted from Chen, Wen, Liu, and Lin (2006).

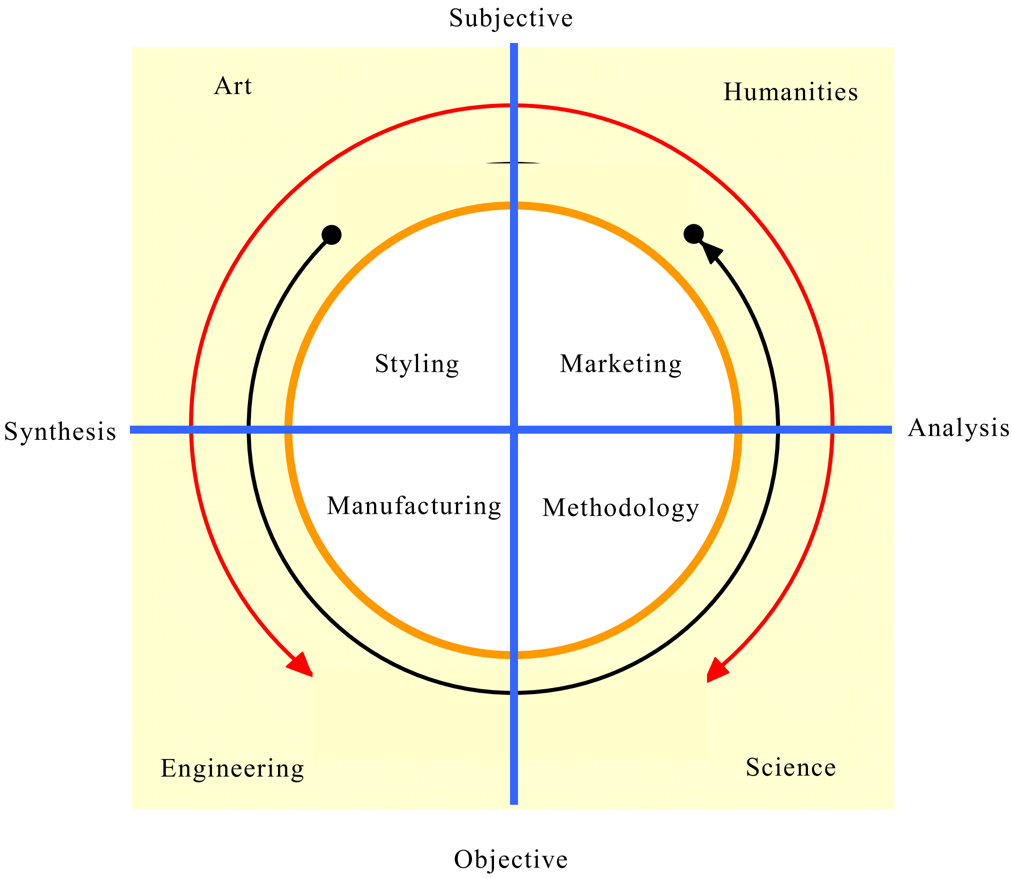
On the contrary, IPs that enable their owners to integrate revenues and to provide visionary values to the firms and their customers arguably have much higher values than the others. The acquisition and creation of such IPs presumably requires market insights, system integration capabilities, R&D efforts with a long-term perspective, and a strong science base, hence tends to be beyond the reach of OEM/ODM manufacturers.

There is increasing awareness that design can be an important factor to product evaluation by consumers (Cooper and Kleinschmidt, 1987) and to product innovation (Leonard and Rayport, 1997) and branding (Beverland, 2005; Danzig, 2002). However, design may remain a fuzzy term, meaning something different to various industrial players.

Among ODM manufacturers, design is often associated with “design to order”, which may be part of their R&D efforts to meet the contract work for brand marketers. Typical design-to-order (or R&D) activities performed by ODM manufacturers are divided into five stages; namely engineering sample (ES), engineering valuation test (EVT), design valuation test (DVT), production valuation test (PVT), and mass production valuation test (MVT). As put by a senior manager at a Taiwanese ICT firm, “design to order is equivalent to design for manufacturing and for volume. What ODM manufacturers do is package the existing technologies and components, frequently with some customised modifications, to meet the concept design proposed by the brand marketer”.

However, design nowadays is much more than that, especially from branding firms’ viewpoint. According to the ICSID (International Council of Societies of Industrial Design), “design is a creative activity whose aim is to establish the multi-faceted qualities of objects, processes, services and their systems in whole life-cycles. Therefore, design is the central factor of innovative humanisation of technologies and the crucial factor of cultural and economic exchange”. The broad view of design covers a wide range of activity encompassing aesthetics, ergonomics, ease of manufacture, efficient use of materials, and product performance and a variety of functions relating to marketing, such as promotional materials, image and logo, brands, interiors, architecture, and the consumer-firm interface (Beverland, 2005). As shown in Graph 21, the design model proposed by Doublin (1983) incorporates a wide range of purposes (manufacturing, styling, marketing and methodology), with each of requiring different domain knowledge (engineering, art, humanities and science), and perhaps a mix of them. However, what is typically performed by an ODM manufacturer is design for manufacturing, giving rise to a substantial capability gap, including design for marketing and design for value-creation during its transformation towards a branding firm.

Graph 21: A Design Model of Multi-dimension



Source: Adapted from Doublin (1983).

It should be noted that the above analyses are not meant to play down the Taiwanese computing/communications firms' quest for R&D and innovation. As a matter of fact, Hon Hai alone is not only the largest US patent owner in Taiwan but also the leading player worldwide in international patenting for connectors. The nature of Hon Hai's patents as well as some other firms' has even gone beyond defensive and cost-saving IPs. However, for many of the Taiwanese OEM/ODM manufacturers and specialised component providers, their core skills in R&D have much to do with their positions within the global production/innovation network.

On the other hand, within the IC manufacturing subsector, Taiwan's IC foundries tend to enjoy leading edges in R&D and capabilities. UMC and TSMC are currently about half a year or a year behind the global leader, Intel, in terms of technological milestone. Both of them are working with Sematech as members on the next generation technologies of 450mm. In fact, TSMC's lawsuit against Semiconductor Manufacturing International Corp. (SMIC), China`s leading IC foundry for the infringement of TSMC's IPs, has recently led to a settlement between the two firms, with SMIC to compensate TSMC with US$200 million cash and certain amount of the company`s shares, plus stock options. This not only could make TSMC the second largest shareholder of SMIC but also gives TSMC a strong market foothold in the Chinese market.

CHAPTER 4. NATIONAL INNOVATION SYSTEMS

4.1. National and Regional R&D and Innovation Policies

The national innovation system (NIS), as a widely-accepted analytical framework for industrial innovation on a national scale, draws attention to the importance of networks and links between diverse institutions as a major factor behind the innovative capacity of a nation. The way these diverse institutions interact with one another within the NIS may be affected by the incentive schemes and institutional arrangements and may thus lead to different innovation performances (Freeman, 1987; Lundvall, 1992; Nelson, 1993).

In a pioneer study on Taiwan's NIS, Hou and San (1993) drew attention to, among other things, the role played by such a government-sponsored research institute as the ITRI in promoting Taiwan's ICT industry, by forging technological alliances with foreign partners and local universities. In 2004, the government sector (ITRI included) accounted for 23.2% of the national R&D expenditure in terms of the source of performance, but this ratio had decreased to 16.8% in 2008. Indeed, Taiwan's ICT industry as a whole has moved from a focus on foreign technology to indigenous innovation (Wu, et al., 2003), even outperforming ITRI in terms of R&D capacities and capabilities. Regarding R&D inputs, Taiwan's R&D intensity (R&D/GDP) has increased from 2.08% in 2001 to 2.77% in 2008 (see Table 15), with above 70% of the national R&D expenditure being attributed to the ICT industry (see Graph 22 and Graph 23), indicating that Taiwan is highly specialised in ICT R&D even compared to many peer countries (see Graph 24). In addition, in terms of US patenting, Taiwan has ranked fourth for eight years in a row (1999-2007) (for details see Table 16).[21] In sharp contrast, Taiwan has been faced with a huge and increasing deficit in technological trade. In other words, Taiwan's achievement in international patenting is not proportional to its trade balances in technology, a phenomenon termed by Chen (2007) as "innovation paradox".

Table 15: R&D Expenditure Indicators of Taiwan

Item \ Year	2004	2005	2006	2007	2008
R&D Expenditure (Million N.T.$)	263,271	280,980	307,037	331,386	351,405
R&D Expenditure as a Percentage of GDP (%)	2.32	2.39	2.51	2.57	2.77
R&D Expenditure by Source of Funds (%)					
Business Enterprise Sector	64.8	66.9	67.2	68.8	70.4
Government Sector	33.6	31.5	31.4	29.9	28.2
Other Domestic Sectors	1.6	1.5	1.4	1.3	1.3
Abroad	0.0	0.1	0.0	0.0	0.0
R&D Expenditure by Source of Performance (%)					

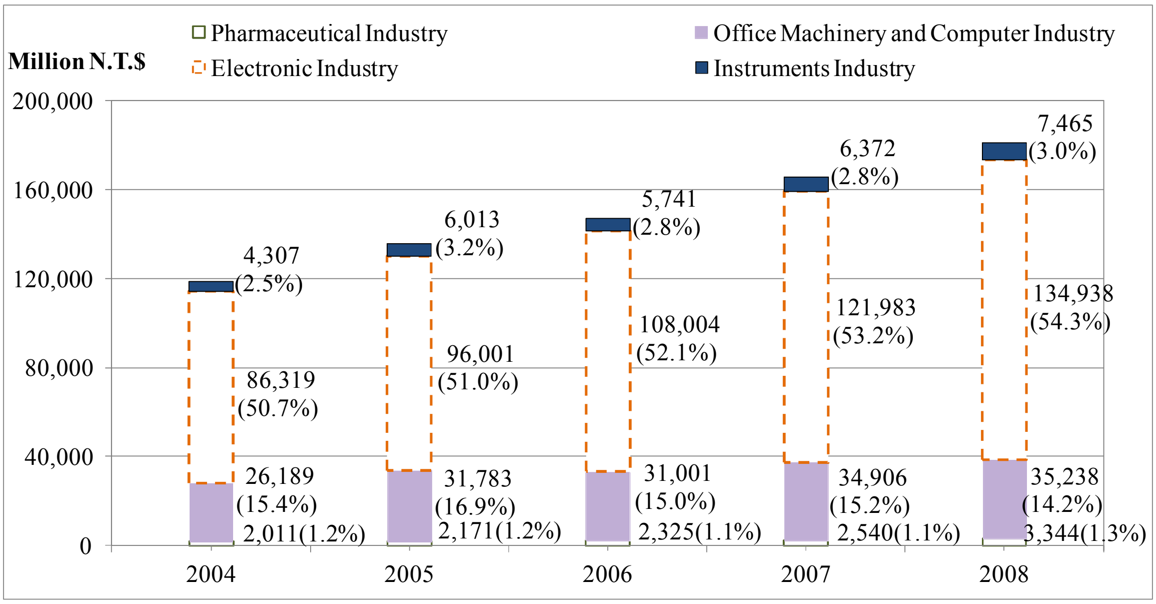
[21] The authors are aware of the fact that international patenting of firms can be a location or country-specific decision. Because the Taiwanese ICT firms as a whole have a strong connection with the USA in terms of market and value chain relationships, they tend to file international patents in the USA.

Item \ Year	2004	2005	2006	2007	2008
Business Enterprise Sector	64.7	67.0	67.5	69.1	70.7
Government Sector	23.2	21.0	19.9	18.3	16.8
Higher Education Sector	11.5	11.4	12.2	12.2	12.2
Private Non-profit Sector	0.6	0.5	0.4	0.4	0.3
Basic Research Expenditure as a Percentage of R&D Expenditure (%)	11.3	10.3	10.2	10.0	10.2
BERD/Value added in Industry (%)	1.91	2.04	2.16	2.26	2.51

Data Source: GDP-National Statistics (http://eng.stat.gov.tw/), Directorate-General of Budget, Accounting and Statistics, Executive Yuan (DGBAS).

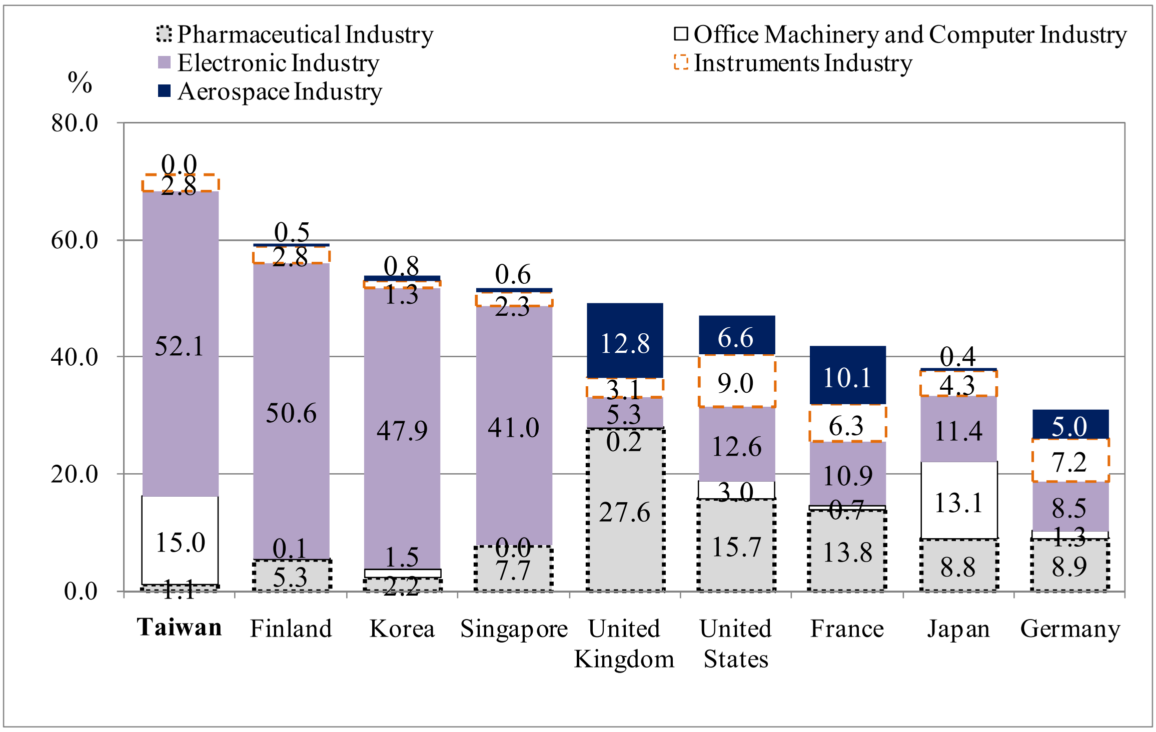
Notes: 1. Other Domestic Sectors include Higher Education sector and Private Non-profit sector.
2. Value added in Industry are calculated from National Accounts by DGBAS, and in accordance with the industrial scope of OECD definition.

Graph 22: R&D Expenditure and Percentage of BERD Performed in the High Technology Industries of Taiwan



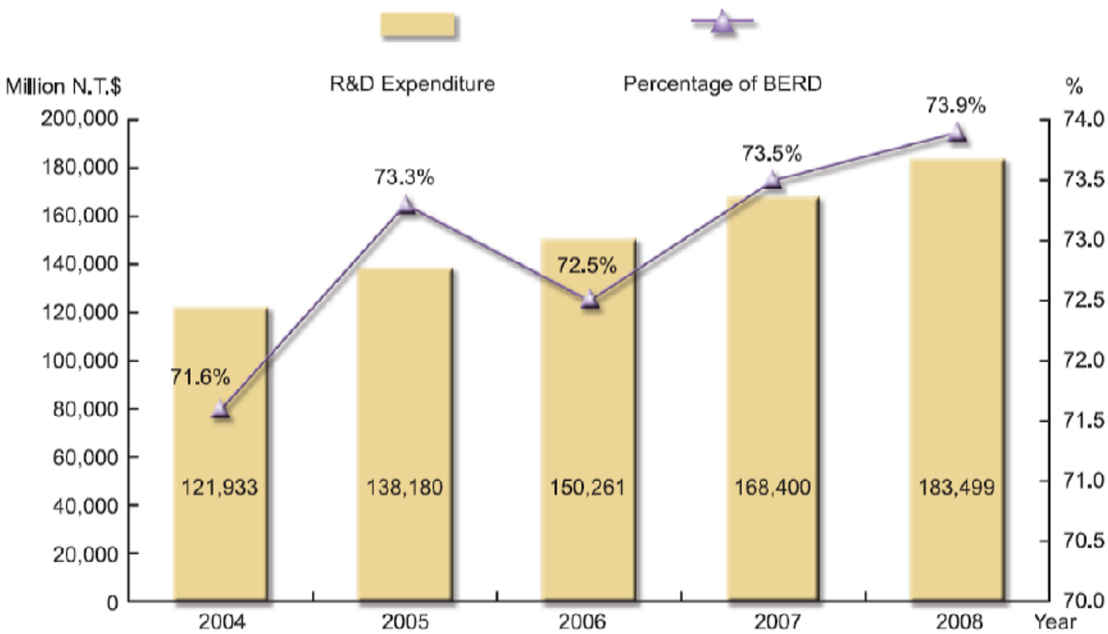
Source: National Science Council, (2010). Indicators of Science and Technology, Taiwan, 2009. Website: http://www.nsc.gov.tw/tech/index.asp (accessed 2010/10/4).

Graph 23: Percentage of BERD Performed in the High Technology Industries, 2006



Source: Countries except ROC: Main Science and Technology Indicators, 2009/1, OECD.

Graph 24: R&D Expenditure in Information and Communications Technology Industries of Taiwan



Source: National Science Council, (2010). Indicators of Science and Technology, Taiwan, 2009. Website: http://www.nsc.gov.tw/tech/index.asp (accessed 2010/10/4).

Table 16: Taiwan's World-Wide Ranking in US Patenting

All patents: 2008			Utility patents: 2008			Design patents: 2008			Utility patents per million inhabitants 2008		
Ranking	Country	Patent Number	Ranking	Country	Patent Number	Ranking	Country	Patent Number	Ranking	Country	Patent Number
1	USA	92,000	1	USA	77,501	1	USA	13,713	**1**	**Taiwan**	**274**
2	Japan	36,679	2	Japan	33,682	2	Japan	2,767	2	USA	264
3	Germany	10,086	3	Germany	8,915	**3**	**Taiwan**	**1,423**	3	Japan	255
4	S. Korea	8,731	4	S. Korea	7,549	4	S. Korea	1,159	4	Israel	164
5	**Taiwan**	**7,779**	**5**	**Taiwan**	**6,339**	5	Germany	976	5	Finland	157
10	China	1,874	12	China	1,225	8	China	647	-	China	0.92

Source: Based on data from USPTO, compiled by TIER.

The so-called "innovation paradox" portrayed above may be attributed to some characteristic features of Taiwan's NIS and the ICT sector. First of all, Taiwanese ICT firms are generally characterised by vertical disintegration and are deeply involved in OEM contacts for brand marketers; thus, individual firms specialise in a specific industrial and technological segment and may tend to focus their R&D efforts on incremental technological change in relation to a specific technological trajectory, leading to the rapid proliferation of patents. Secondly, following closely on from this, Taiwan's ICT firms tend to pursue technological innovation on the pathway led by the architectural design created by leading brand marketers and/or industrial standard setters. As a result, the more their production volume expands, the more royalties they pay to the brand marketers and/or industrial standard setters (for example CD-ROM royalties paid to Philips) (Chen, 2007).

It is interesting to note that for Taiwan the ICT sector's GDP share is not proportional to its BERD share, as discussed in Introduction Section. The ICT sector as a whole, including both manufacturing and services, accounted for about 10.71% of Taiwan's GDP, while the BERD share related to ICT was so high as above 70%.[22] The underlying reasons may be associated with the following factors.

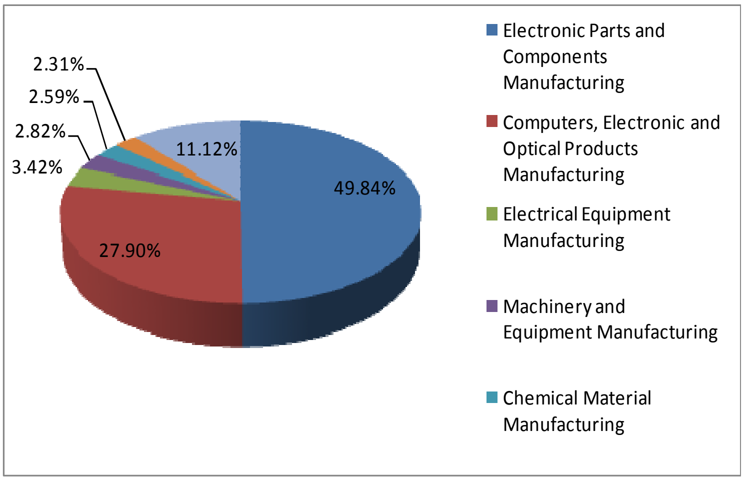
Firstly, both the IC and LCD industries have approached the technological frontiers, entailing a substantial increase in R&D investment. For example, two leading Taiwanese players in the semiconductor industry, UMC and TSMC are currently about half a year or a year behind the global leader, Intel, in terms of technological milestone. The introduction of 450mm, or even 350mm process technologies for both of the firms demands a large amount of R&D

[22] It should be noted that R&D expenditure in the service sector has been underestimated in Taiwan. According to "Indicators of Science and Technology, Taiwan", compiled by the National Science Council (NSC), R&D expenditure in the service sector was just about 7.5% of Taiwan's total GERD. However, this figure was based on a limited coverage of the service sector for the National Survey of R&D Activities at Business Enterprises, conducted by the NSC.

investment. For the Taiwanese LCD industry, its mainstream production capabilities and capacities are just about 7.5-generation or 8.5-generation fabs, still behind the new frontier of tenth-generation, led by Samsung and Sharp. However, there has been a trend for the producers of LCD panels to integrate part of the used-to-be-vertically-disintegrated value chain under their control, for example Driver ICs and Colour Filters, even with the introduction of 7.5-generation or 8.5-generation fabs. As a result, they are also obliged to increase their R&D investment. The ICSS Census for 2006 provided evidence to support this point. Over the period 2001-2006, the R&D investment of the private sector increased by NT$134.82 billion,[23] 88.09% of which was accounted for by two subsectors, namely the electronic component sector (55.75%), mainly comprising the "Two Trillion Industries", and the computer, electronic product & opto-electronic product sector (32.34%) (see Graph 25).

Graph 25: Taiwan's Manufacturing R&D in 2006, by Sector

Sector (at the 2-digital level)	R&D Expenditure
Total of Manufacturing R&D	281,513
Electronic Parts and Components Manufacturing	140,310
Computers, Electronic and Optical Products Manufacturing	78,537
Electrical Equipment Manufacturing	9,632
Machinery and Equipment Manufacturing	7,936
Chemical Material Manufacturing	7,281
Motor Vehicles and Parts Manufacturing	6,510
Other Manufacturing	31,307



Note: The subsectors are classified at the two-digital level. The definition of R&D expenditure is more broadly defined than that of the Frascati Manual.

Source: Data taken from the Industry, Commerce and Service Sector Census, compiled by CIER.

A second factor is about the structure of the GIN in the ICT sector and the role of R&D performed by the Taiwanese players within the GIN. In general, Taiwan's ICT sector is characterised by vertical disintegration and the pursuit of OEM/ODM contracts for brand marketers. As a result, the brand marketers tend to focus their R&D mainly on product concept initiation and product architecture, thus delegate part of their R&D functions to their Taiwan-based ODM suppliers, giving rise to offshore collaboration and inter-organisational concurrent development. In other words, such offshore collaboration tends to take the form of inter-organisational, cross-border collaboration for innovation. Therefore, the Taiwan-based ODM suppliers may have to set up different R&D teams to serve different customers. In order to protect their individual customers' industrial secrets, those R&D teams within the individual Taiwan-based ODM suppliers are literally prohibited from interactions with each other, leading to the duplication of the R&D investment on the part of the Taiwan-based suppliers. For example, Quanta, the leading ODM suppliers of notebook computers has at least six R&D teams, serving different brand marketers. This situation applies to not only the

[23] It should be noted that the definition of R&D expenditure adopted by the ICSS Census for 2006 tends to be broader than that of the Frascati Manual.

system products but also the key components. For instance, the Taiwan-based manufacturers of Inverters for LCD TVs also have to follow suit in order to provide customised solution to different branding firms of LCD TVs. In addition, in the GPN woven by the Taiwan-based ODM suppliers, quite a number of them have now scaled down their local manufacturing/assembly operations and handed over to their offshore sites in China and elsewhere. Following this, the "de-linking of manufacturing and R&D in terms of location" has become the prevailing practices, with the headquarters in Taiwan mainly performing administrative operations and R&D functions, while their offshore subsidiaries conducting manufacturing/assembly operations, leading to a division of labour, featured by pilot run vs. mass production across the Taiwan Strait. As a result, OEM/ODM contracts performed by the Taiwan-based suppliers tend to generate limited local value added arising from manufacturing/assembly for Taiwan.

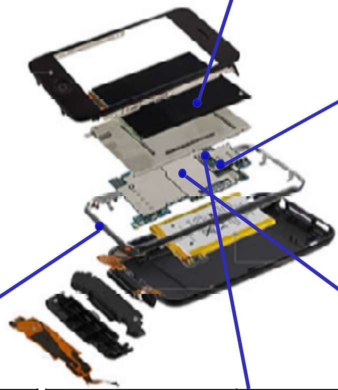
On the other hand, the Taiwanese ICT players can be regarded as an important catalyst in the introduction of brand new or generations of ICT products to the global market. Taking notebook computers as an example, the Taiwanese firms have served the top three brand marketers (HP, Dell and Apple) as major innovators and suppliers of the key components and parts needed and integrated hubs of production and logistics networks (see Graph 26). It has become a norm for such players as Hon Hai, Quanta, Wistron and Inventec to follow a 98-2 formula of "global logistics" set by the leading brand marketers, requiring them to deliver 98% of the Build-to-Order volume to the end customers within two days after the order issued. Therefore, both parties, together with suppliers of components and parts have to work closely right from the beginning in order to develop and design different generations and varieties of notebook computers. Moreover, underlying Apple's success in iPhones are various supports from a number of the Taiwanese ICT firms' efforts in R&D as well as the deployment of production and logistics networks (see Graph 27). Taken all these together, it can be argued that from the perspective of the ICT industry, Taiwan's NIS is closely linked with the GIN led by the brand marketers.

Graph 26: The Role of the Taiwanese ICT Firms for the Top Three Brand Marketers in Notebook Computers

		DELL	APPLE	HP
The role of the Taiwanese ICT firms	Innovator of key components (Share by production value)	65%	50%	65%
		LCD, Keyboard, Chassis, AC adapter and Wireless LAN Module, etc.		
	Resource integrator (Major system integrators) (Efficiency of global logistics)	Compal , Wistron	Quanta, Hon Hai	Quanta, Inventec
		98-2 formula of global logistics: To deliver 98% of the Build-to-Order volume to the end customers within two days after the order issued		
	Logistics hub (Share of total shipments)	95%	100%	95%

Source: Based on information provided by MIC, III (2009).

Graph 27: The Global Innovation Network of Apple's iPhones and the Role of the Taiwanese Firms



Components	Main Supplier
Display	Sharp, TMD
Touch Panel	Wintek, TPK

Components	Main Supplier
Baseband	Infineon
WCDMA PA	TriQuint
GSM/EDGE PA	Skyworks
Application Processor	Samsung
Mobile DDR DRAM	Samsung
NOR Flash	Numonyx
NAND Flash	Samsung, Toshiba
Bluetooth	CSR
A-GPS	Infineon
SAW Filter	TXC
Power Management IC	Infineon, NXP

Components	Main Supplier
Connector	Foxlink, Advanced Connectek
PCB	Unimicron, Nan Ya PCB, Compeq
FPC	M-Flex, Mektron, Fujikura, Flexium Interconnect, Foxconn Advanced Technology

Components	Main Supplier
Casing	Foxconn Technology
EMS	Hon Hai Precision

Components	Main Supplier
3.2-Megapixel CIS	OmniVision
Camera	Largan Precision

Note: The Taiwanese firms are underlined.
Source: Based on information provided by MIC, III (2009).

Without denying its significance to the GIN, there are concerns in Taiwan that Taiwanese ICT industry, particularly the computing/communications subsector is subject to some bottlenecks. First of all, the industry is facing an era of razor-thin profit, as discussed above. Secondly, Taiwanese ICT industry is short of capabilities to define and create the dominant architecture design for new generations of ICT products, which in turn may lock it into the trajectory of OEM/ODM manufacturing. Thirdly, due to its overconcentration in the ICT sector, especially its intermediate goods in terms of domestic production, Taiwan may become particularly vulnerable to the downturn of the global economy. This has proven to be the case during the recent global financial crisis, when Taiwan's ICT industry, particularly the DRAM and LCD subsectors, was severely harmed because of the "Bullwhip effect".

To overcome the above-mentioned bottlenecks, the government has formulated a few policies to facilitate the transformation of Taiwan's ICT industry. Firstly, in line with the trend towards blurred boundaries between manufacturing and services, the "servitization of manufacturing" (also known as industrial services, servicizing) has surged as an important thrust of transformation for an increasing number of manufactures. The government in Taiwan is actively promoting such transformation in the manufacturing sector, particularly the ICT sector. An important aspect of the Servitization of Manufacturing Programme is, taking advantage of the current strengths of Taiwanese ICT supply chain, to create new service opportunities for manufacturing and eventually provide global market with the offering of "one-stop-shopping services". Three pillars form the core the program, including: (i) strengthening of customer value by encouraging companies to add more service elements from the perspective of customer in order to increase customer satisfaction, customer relationship and added-value; (ii) extending of manufacturing value by encouraging manufacturers, based on their core competencies, to develop service-oriented offering; (iii) creating new service business by assisting manufacturers to develop advanced application type of service-oriented offering. In fact, as discussed in Chapter 2, among some other firms, Quanta is transforming itself from a manufacturer of notebook computers to a provider of a set of comprehensive total solution, termed “Service by Integration”. Quanta intends eventually to progress further towards the direction of “Service by Innovation”, with an aim to create value and profits with services. Secondly, the government is also promoting such new fields as Cloud Computing and car electronics, with an aim to facilitate the diversification of the ICT industry. With particular regard to Cloud Computing, the Ministry of Economic Affairs (MOEA) has reached agreements with a couple of MNCs, Microsoft and IBM for example, to develop the technologies and applications needed, in cooperation with some local universities and research institutes. In addition, Hon Hai’s diversification strategy involves tapping China`s domestic market by exploring the potential of the solar-cell manufacturing sector.

In addition, the promotion of ICT applications has been put top on policy agenda in Taiwan, especially recently referring to the “Living Lab” model, which has also been actively adopted in the EU to take advantage of the strengths of Taiwan's ICT industry, the DoIT at the MOEA has launched the i236 Initiative, which aims for Taiwan to become a living lab for the application of smart technologies in areas such as comfort and convenience, agriculture and leisure industries, safety and disaster prevention, medical services, sustainable energy, and ubiquitous environment (see Graph 28). Another example is the Telematics Technology Development Plan, which improves traffic flow by integrating data from dedicated short-range communications between cars and between the car and the road infrastructure. These initiatives and other innovative services will serve to improve the quality of living in Taiwan and expand the international market development for Taiwanese enterprises.

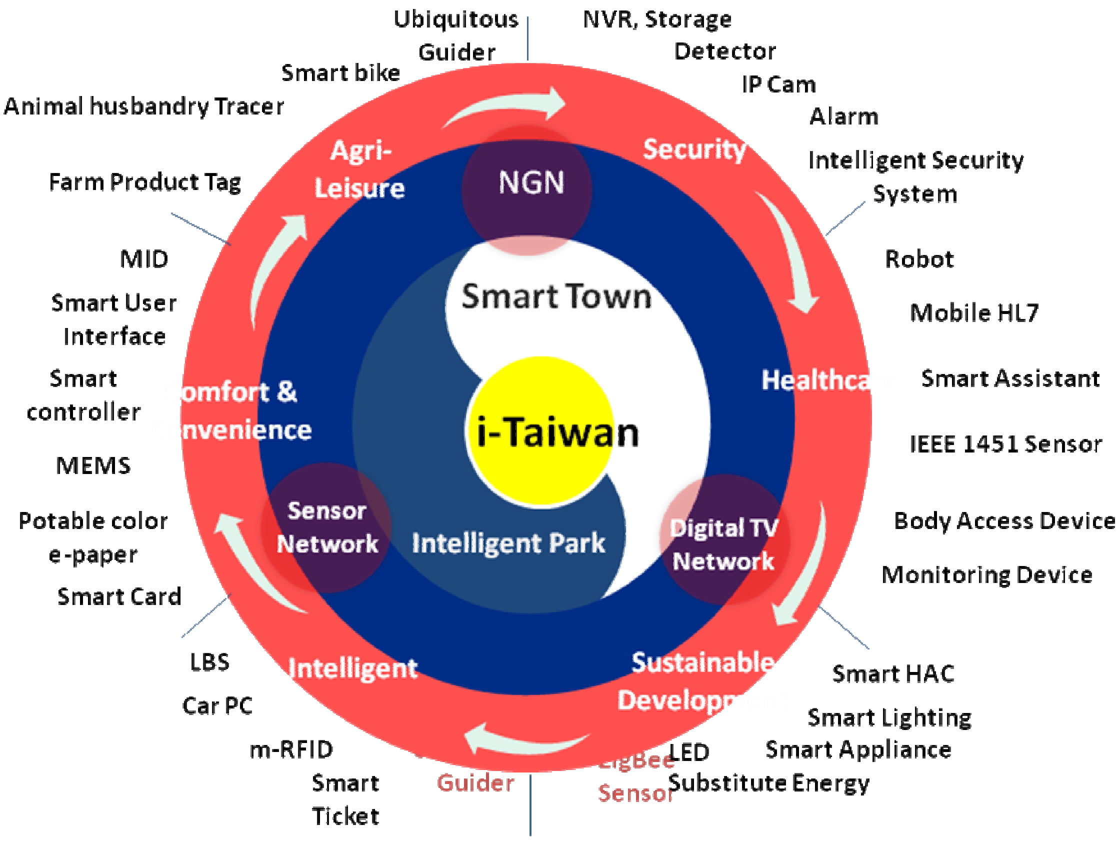
Another set of governmental initiatives that are closely relevant to the transformation of Taiwan’s ICT industry is about Taiwan’s new policy thrusts towards China. China has gone beyond a manufacturing powerhouse, with the potential to move gradually towards a regional technological superpower. Also, the economic ascendancy of China has been strengthened by the recent financial crisis. Taiwan has to come to terms with this reality by realigning its industrial science and technology development and the relevant policy addressing the cross-strait issues. Set against the above backdrop, such new initiatives as cross-strait cooperation in industrial standards, the Building Bridges Project, ECFA (Economic Cooperation Framework Agreement)[24] and the deregulation of Chinese investment in Taiwan have been launched mainly from the Taiwan side and met with some positive responses from China.

In particular, the Building Bridges Project has gained momentum through the establishment of platforms for a number of industrial sectors, based upon which constructive dialogues between the two sides of the Taiwan Strait have taken place. In addition, the initiative to promote cross-strait cooperation in industrial standards has continued for several years. This effort coincides with widely-publicised strategies to promote indigenous innovation and industrial standards in China. A few areas have been identified as the priority themes for cross-strait cooperation in industrial standards, with mutual consensus of going beyond dialogues and standard harmonisation. To a certain extent, these initiatives are relevant to the future development of Taiwan’s ICT industry. For example, for cross-strait cooperation in industrial standards, both sides have reached agreements to work together on the fields of TD-SCDMA, LCD, LED and solar cells. As far as Taiwan is concerned, cross-strait cooperation in industrial standards is meant to come to terms with the rise of China and promote cross-strait economic relationships beyond the current typical form of Taiwan-based firms’

[24] ECFA is a special free trade agreement between Taiwan and China, which was concluded in September 2010.

relocation of industrial value chain to China. As a result, some of the Taiwanese ICT firms may be able to get involved in the formation of the Chinese industrial standards and/or dominant architecture design at the early stage.

Graph 28: The Profile of i236 Initiative in Taiwan



(2 themes, 3 networks, 6 applications)

Source: DoIT, MOEA

4.2. Comparative Advantages of Innovation Systems

An important aspect of R&D internationalisation involves a process of increasing disintegration of innovation capabilities around the globe, resulting in the fact that some, if not many, of the indigenous firms and/or industrial clusters in the developing world are nowadays able to shoulder important functions that used to be undertaken by their counterparts in the developed world. In particular, both production and R&D outsourcing has become a widely adopted practice in quite a number of industries as a means of enabling leading players and brand marketers to remain cost-competitive. Within this process, brand marketers are becoming closely linked to their first-tier suppliers in terms of innovation capabilities. Based on their indigenous capabilities accumulated through long-standing contract work for the brand marketers, the Taiwanese ICT firms are nowadays deeply involved in the collaborative research and design process led by the brand marketers. This may call for the MNCs to relocate their R&D facilities to get close to their first-tier suppliers in Taiwan. Such cases as the Dell Taiwan Design Centre and the IBM xSeries Taiwan R&D Centre are exemplary with regard to these points (Chen, 2007). To give an example, the IBM xSeries Taiwan R&D Centre is mandated as the 'mission lab'[25] for IBM's low-end servers, the only one server R&D centre outside the USA, with the R&D headquarters in Raleigh, together with R&D facilities in Kirkland and Austin, being in charge of high-end servers.

In other words, in the ICT industry, as the network flagships have become hollowing-out (Kotabe, 1996), part of their innovation offshoring tend to take the form of farming out to layers of specialised suppliers. The MNCs may therefore feel more comfortable in capitalising on the strengths of Taiwan's NIS by establishing offshore R&D centres. As a senior manager of the Dell Taiwan Design Centre put it, "when the majority of products are already being manufactured in Asia, Dell's R&D centre in Taiwan allows R&D engineers to get even closer to the centre of action and better able to achieve Dell's ability to respond rapidly".

Such cases are not limited to the existing ICT sub-sectors and/or technologies. With its current strengths, Taiwan's ICT industry is also collaborating with leading foreign players in emerging technologies and fields. For example, Microsoft has joined force with Taiwan to conduct R&D in Cloud Computing and new related generations of devices, for which Taiwan may participate in the development of Cloud Computing servers, new chips, software and applications required. Likewise, Dell has also expanded its R&D centre in Taiwan, given R&D mandates for Cloud Computing. In another example, ASML, the global second largest semiconductor equipment manufacturer has recently established in Taiwan a production plant and an R&D centre for Lithography, first of its kind in Asia, in order to take advantage of the booming IC sector in Taiwan. Together with ASML, some other global leading players in semiconductor equipment, such as Lam Research and Tokyo Electron Limited (TEL) also set up international training centres in Taiwan.

In addition, Taiwan's ICT sector is featured by vertical disintegration in industrial structure, but with strong R&D and innovation capabilities, as evident in US patenting. This may make collaboration with Taiwanese ICT firms more attractive to many MNCs. As argued by Saxenian (1997), apart from the cross-Pacific ethnic social network, the similarity in industrial structure made networking between Silicon Valley and the Hsinchu Science Park, much easier and more intensive. This is particularly true in the case where the GIN has become a prevailing mode of industrial organisation.

Moreover, Taiwan has since 1999 been implementing the National Science and Technology Programme, which is featured by inter-ministerial coordination, long-term and handsome funding commitment, upstream and downstream integration, and cross-actor (the industry, academia and research institutes) cooperation, with an overall aim to promote systemic innovation for industrial development and social well-being. So far there are nine fields sponsored by National Science and Technology Programme, including e-learning, nanotechnology, telecommunications, SOC. Also underlying the National Science and Technology Programme is a purpose to establish Taiwan as centres of excellence in a few individual fields, which may serve as a base for international cooperation.

[25] In IBM, a mission lab is positioned to shoulder the entire R&D process for its product mandates. For details, please refer to the IBM case study in Section 3.2.1.

CHAPTER 5. OUTLOOK FOR THE FUTURE AND THE CONCLUSIONS

5.1. Main Conclusions of the Key Trends

Ever since the 1980s, the ICT industry has been the paramount engine of economic growth in Taiwan. A number of Taiwanese-made ICT hardware products have enjoyed a significant global market share. Behind this development are the well-regarded production and design capabilities of the Taiwanese ICT producers, which in turn have made Taiwan a major source of contract work for international prominent ICT firms.

Taiwan is highly specialised in the ICT sector, in terms of manufacturing GDP, exports, and more importantly R&D expenditures. The high technology sector as a whole accounted for 32.14% of manufacturing GDP in 2006. More importantly, the lion's share of the high technology sector (31.36% of manufacturing GDP) is associated with the ICT sector. Out of 39.44% of manufacturing exports by the high technology industry, 39.14% can be attributed to the ICT sector. Even more significant is a high concentration of Taiwan's manufacturing R&D in the ICT sector, accounting for 69.85% of Taiwan's manufacturing R&D.

Both FDI and technology transfer from the advanced countries, particularly the USA and Japan triggered the local firms' entry into the different subsectors over time, from the computing/communications manufacturing, IC and more recently to LCD subsectors. However, the local firms have managed to establish strong technological and innovation capabilities through internal R&D, technology transfer from local research institutes, the tax credit scheme and the establishment of science parks – first the Hsinchu Science Park, and later several others. The Hsinchu Science Park has in fact developed into the centre of gravity for the local ICT industry, generating agglomeration effects that have allowed the ICT industry to exploit the benefits of proximity and outsourcing. Therefore, even though they specialise in one segment of the value chain, ICT firms in Taiwan are networked by social and business connections. In addition, both of Southern Taiwan Science Park and Central Taiwan Science Park have developed into two new clusters for the IC and LCD sectors mainly because of the constituent firms' relocation and/or expansion from the Hsinchu Science Park.

Taiwan's IC industry is organised as an industrial network system with a strong connection to Silicon Valley. Behind this exchange were overseas Chinese and Chinese expatriates, who played an important role in establishing the trans-Pacific social and business networks that proved crucial in connecting Taiwan's production system with advanced market knowledge and technology. Apart from the ethnic social network, the similarity in industrial structure made networking between Silicon Valley and the Hsinchu Science Park, much easier and more intensive.

However, the development of Taiwan's ICT industry as a whole has gone beyond the paradigm of local clustering, thanks to the formation of the GPN and more recently the GIN. This has had much to do with the growing popularity of outsourcing and offshoring adopted by the brand marketers. In line with this trend, Taiwan's computing/communications manufacturing industry has, since the late 1980s, outreached in terms of production and more recently even R&D. The offshore production of Taiwan-based computing/communications firms right now far outweighs their domestic production. In terms of domestic production, the role played by Taiwan's ICT industry in the GPN has shifted from being a key producer of end products to that of important components and parts (intermediate goods) manufacturer.

This development cannot be reduced to the argument that Taiwan-based ICT end product producers have lost the edge to their international competitors: instead it should be interpreted within the context of the GPN.

Major brand marketers' adoption of outsourcing and order-based production has greatly rationalised their global supply chain, and hence altered their contractual relationships with Taiwanese counterparts. Such contractual arrangements have prompted Taiwan's ICT firms to upgrade their position within the global production system. As a result, Taiwan's ICT firms participate in cross-border supply-chain management, logistics operations, and after-sales services, requiring them to form a fast-response global production and logistics network.

More importantly, China has become an increasingly important offshore production site for Taiwan-based PC and notebook computer firms. The outreach of Taiwan's ICT firms has fuelled China's growing significance in the assembly and manufacturing of ICT products. There are even signs that China is increasingly playing a growing role in R&D. Characteristic features of the GPN include cross-border modularised production and fast, patchy production, instead of production under one roof and mass production as before. Therefore, from the standpoint of Taiwan's ICT producers, the triangular linkages involving Taiwan, China, and the USA may mean much more to their prosperity than does the local industrial cluster in Taiwan.

The ICT sector has also played an important role in Taiwan's exports. Taiwan's trade balances generated by the six categories of ICT goods increased from NT$348.24 billion in 1997 to NT$902.16 billion in 2006, which was about 1.34 times of the total trade balances (NT$674.98 billion) for that year. Referring to the breakdown of ICT goods, there has been a substantial shift in the export structure of Taiwan's ICT goods. In a word, Taiwan's ICT exports are now highly concentrated in ICT intermediate goods.

Taiwan's ICT device industrial clusters have co-evolved with their international counterparts, hence local agglomeration alone can no longer adequately account for the dynamics of Taiwan's ICT device industry. Because of the formation of the GPN, domestic production in Taiwan tends to concentrate on "intermediate goods" such as IC and LCD, most of which are exported overseas to manufacturing hubs of ICT end products, particularly China. However, most ICT firms, particularly IC and LCD manufacturers, continue to locate their R&D bases in Taiwan. This together with the IC design industry makes Taiwan an innovation hub for the global ICT production network.

Referring to information on top 20 firms scoreboard of sales, R&D, and US patents, we find that the OEM/ODM manufacturer group accounts for more than 50% (51.27%) of the combined sales of the top 20 firms. In addition, about three quarters (75.33%) of the combined sales can be attributed to the computing/communications subsector as a whole. In sharp contrast, when it comes to R&D expenditures, the IC subsector stands out, accounting for 50.28% of the combined R&D expenditures of the top 20 firms, implying that the computing/communications subsectors as a whole tends to have a relatively low R&D intensity.

However, in terms of the individual subsectors' share of US patents granted, the sectoral distribution is not so biased towards the IC sector. About 48.25% of the total patents granted to the top 20 firms can be accounted for by the computing/communications subsector as a whole. In addition, the patent share for the IC manufacturing group is 22.55%, and 14.20% for the IC design group.

Two important questions arise from the picture portrayed above. First of all, why do the leading IC manufacturers, and even the IC design houses invest so much in R&D? A quick answer to this is that the IC manufacturers, particularly the two foundry firms, are approaching the technological frontiers, entailing a substantial increase in R&D investment. The second question is about the relatively high share of US patents granted to the OEM/ODM manufacturer group and the specialised component supplier group, compared to their lower R&D intensity. This may have much to do with the formation of the GIN, for which part of the network flagships' innovation offshoring tends to take the form of farming out to layers of specialised suppliers.

In terms of micro-level assessment, Taiwan's computing/communications manufacturing subsector has faced an era of "razor-thin profit", bringing about bottlenecks such as slow value added growth, deteriorating value added rates, and a decrease in the industrial linkage effect. These bottlenecks can only be fully comprehended by taking into account a wide variety of factors, both negative (for example, a trend of sharp decline in the price of ICT products, international outsourcing and international division of labour within the GPN, large-scale capital investments and the locked-in effect) and positive (for example, industrial upgrading leading to a rising dependence on foreign key components and equipment).

Nonetheless, the Taiwanese ICT players are not without R&D and innovations. They are strengthening their value creation, particularly with the incorporation of services into their business models, and are demonstrating different profiles from their previous stereotypes. For example, Acer's unique Channel Business Model has been instrumental in the company's latest success, and it is trying to overtake Dell to become the second-largest computer brand in the world. Even Compal, an ODM vendor has positioned itself to know the end customers better than the brand marketers do in order to better serve the latter and position itself closer to the end market.

Apart from FDI in production, some of the MNCs in Taiwan have also invested in R&D. In fact, R&D intensity for foreign-owned subsidiaries in Taiwan's manufacturing sector increased from 1.52% in 2002 to 1.94% in 2003, indicating that Taiwan's mandate has significantly improved in terms of MNCs' regional or GINs. It is possible to characterise those foreign R&D subsidiaries with a higher R&D intensity in Taiwan. Foreign-owned firms in Taiwan with a higher export propensity tended to be more R&D intensive. Foreign-owned subsidiaries with higher R&D intensity are also characterised by a greater degree of localisation in terms of their sourcing of both production materials and capital goods. This is particularly true for ICT brand marketers which have relied substantially on local sourcing in Taiwan.

In addition, the government has orchestrated a plan to encourage MNCs to establish R&D centres on the island, which since its implementation in 2002 has met with some success. In Taiwan there are so far some 46 R&D centres, established by 34 different MNCs. Of note is the fact that these R&D centres are related mainly to the current strength of Taiwan's industrial development, with the lion's share (67%) being focused on the broadly defined ICT area and showing a strong intention of collaborating with the local firms. This may have to do with the position of Taiwan's ICT industry within the GPN and GIN. In the case of the HP, IBM, and Motorola, the major players in Taiwan's ICT industry can be regarded as these companies' first-tier suppliers and/or ODM partners. As for the Microsoft Technology Centre, Microsoft provides essential platform technologies to the local ICT industry, based on which the latter may develop new products for the international as well as domestic markets. However, the role played by the offshore R&D facilities in this case has gone beyond the traditional technology transfer units, which tend to perform adaptive R&D to meet local needs, but is by nature in line with the prevailing collaborative research and design model.

Such innovation offshoring is different from the familiar notion of R&D internationalisation which tends to take a position that individual MNCs are the unit of analysis. Regarding the latter, MNCs' offshore R&D is perceived as part of their own international R&D networks, facilitating them to exploit or explore both internal and external resources. However, our version of R&D internationalisation has to do with the current restructuring in the ICT sector on the global scale. Within this process, different layers of industrial players are increasingly required to closely interact with one another for innovation. As part of this restructuring, this externalisation of innovation no longer stops at the national border, involving the reconfiguration of MNCs' international R&D networks.

Along with the above trend, Taiwan has been among the top FDI investors in China, with their investment there increasingly involving the R&D function. This trend coincides with the surge of China as a hotspot for MNCs' offshore R&D in the developing world and China's attempt to promote indigenous innovations. A previous study has shown that China had become the major target for these Taiwanese ICT firms' offshore R&D in quantitative, though not necessarily qualitative terms.

Five types of R&D portfolios were identified. First of all, where Taiwan-based firms' production lines are concentrated in China as well as other countries, product development is undertaken in Taiwan, whilst engineering support and manufacturing-related R&D is undertaken in China. This seems to be the major type and often entails the de-linking of R&D and manufacturing in terms of location. Secondly, some Taiwanese ICT firms outsource their software development services from China partly because of the leapfrogging potential of software. The third type of portfolio involves a tendency for some Taiwanese firms to perform their basic research in China, which often involves collaboration with local universities and/or research institutes. The fourth type has some Taiwanese firms performing their upstream (core) R&D within Taiwan, whilst their subsidiaries in China carry out downstream (non-core) R&D. Finally, there are also cases where Taiwanese firms perform R&D in China for systems-related products, often modular products for the local market, such as motherboards for communications systems, whilst performing R&D for peripherals, such as handset motherboards, in Taiwan. As argued by Ernst, "competitive success critically depends on vertical specialisation. Global firms selectively outsource certain capabilities from specialised suppliers and they offshore them to new, low-cost locations". This situation applies to not only the brand marketers but also their Taiwanese OEM/ODM counterparts.

In fact, since the 1990s, MNCs' overseas R&D has also been expanded to the developing world and such countries as India and China have been documented as high-profile host countries for MNCs' offshore R&D facilities. More importantly, the existing evidence tends to suggest that MNCs' offshore R&D mandates have increasingly gone beyond the traditional pattern of technology transfer and adaptive R&D in developing host countries. Christensen, Craig, and Hart have argued that such countries as China and India may bring about "the great disruption" and that "technologies emerging from these countries may have profound but unpredictable implications for the rich world's markets." This seems to suggest that new patterns and flavours have emerged from the current trend towards R&D globalisation, including R&D offshoring, technology sourcing, offshore collaboration, particularly regarding developing host countries. In this way, MNCs' offshore R&D mandates have increasingly gone beyond the traditional pattern of technology transfer and adaptive R&D in developing host countries. Both R&D offshoring and technology sourcing often involve software, basic research, and even new market insights. Offshore collaboration, on the other hand, tends to take the form of inter-organisational, cross-border collaboration for innovation.

It follows that certain rules of the game for R&D and innovation may have begun to change, at least in relative terms. First of all, certain types of R&D internationalisation may involve de-linking of R&D and manufacturing in terms of location, unlike the case of technology transfer and adaptive R&D. This situation implies that MNCs' offshore R&D may not necessarily lead to the creation of a new industrial segment for the host country, hence generating limited spillover effects. Secondly, some of developing countries have increasingly become a source of R&D and innovation, not just a technology recipient and late-adopter. Following this, players in the developing world may serve as partners in collective innovation, with their involvement at the early stage of the product life cycle.

Elsewhere, the authors have put forward a holistic view of the possible R&D portfolio of flagship MNCs on both sides of the Taiwan Strait. In essence, based on the heritage of industrialization in the ICT industry, Taiwan has been able to capitalise on its first-tier supplier advantage as a means of attracting MNCs to set up their offshore R&D facilities on the island. As a result, these MNCs have tended to conduct certain types of R&D in Taiwan, ranging from medium-term product/process applied development, short-term innovation, and prototype development to significant adaptation and improvement to existing technologies. By contrast, while the bulk of foreign R&D in China may be related to adaptive R&D, a few MNCs are conducting strategic R&D in China, such as blue sky or basic research and medium-term product/process research.

Hence, this could give the impression that research conducted by MNCs may mean more to the host country than development does. This impression may be an oversimplification. Instead, development conducted by MNCs in Taiwan often entails close interactions with the indigenous firms, and hence could bring benefits to the local economy in an immediate and direct way. By contrast, results from research conducted by MNCs in China takes time to bear commercial fruit. However, where the research involves emerging technologies and/or industries, it is possible that R&D conducted in China can redefine the technological order across the Taiwan Strait, if not the world. This will become more likely if R&D conducted by MNCs in China eventually goes through the commercialization process by working together with China's indigenous value chain, giving rise to leapfrogging development in China.

Indeed, Taiwan's ICT industry as a whole has moved from a focus on foreign technology to indigenous innovation. Regarding R&D inputs, Taiwan's R&D intensity (R&D/GDP) has increased from 2.08% in 2001 to 2.62% in 2007, with about 67% of the national R&D expenditure being attributed to the ICT industry. In addition, in terms of US patenting, Taiwan has ranked fourth for eight years in a row (1999-2007). In sharp contrast, Taiwan has been faced with a huge and increasing deficit in technological trade. In other words, Taiwan's achievement in international patenting is not proportional to its trade balances in technology, a phenomenon termed as "innovation paradox".

The “innovation paradox” portrayed above may be attributed to some characteristic features of Taiwan’s NIS and the ICT sector. First of all, Taiwanese ICT firms are generally characterised by vertical disintegration and are deeply involved in OEM contacts for brand marketers. Thus, individual firms specialise in a specific industrial and technological segment and may tend to focus their R&D efforts on incremental technological change in relation to a specific technological trajectory, leading to the rapid proliferation of patents. Secondly, Taiwan’s ICT firms tend to pursue technological innovation on the pathway led by the architectural design created by leading brand marketers and/or industrial standard setters. As a result, the more their production volume expands, the more royalties they pay to the brand marketers and/or industrial standard setters.

Of note is the fact that, for Taiwan, the ICT sector’s GDP share is not proportional to its BERD share. The underlying reasons may be associated with the following factors. Firstly, both the IC and LCD industries are approaching the technological frontiers, entailing a substantial increase in R&D investment. For example, two leading Taiwanese players in the foundry industry - UMC and TSMC - are currently about 6 months to a year behind the global leader, Intel, in terms of technological milestones. A second factor is the structure of the GIN in the ICT sector and the role of R&D performed by Taiwanese players within the GIN. The offshore collaboration led by the brand marketers tends to take the form of inter-organisational, cross-border collaboration for innovation. Therefore, Taiwan-based ODM suppliers may have to set up different R&D teams to serve different customers. In order to protect their individual customers’ industrial secrets, those R&D teams within the individual Taiwan-based ODM suppliers are literally prohibited from interacting with each other, leading to the duplication of the R&D investment on the part of the Taiwan-based suppliers.

In addition, in the GPN woven by the Taiwan-based ODM suppliers, quite a number of them have now scaled down their local manufacturing/assembly operations and handed over to their offshore sites in China and elsewhere. Following this, the “de-linking of manufacturing and R&D in terms of location” has become the prevailing practices, with the headquarters in Taiwan mainly performing administrative operations and R&D functions, while their offshore subsidiaries conducting manufacturing/assembly operations, leading to a division of labour, featured by pilot run vs. mass production across the Taiwan Strait.

On the other hand, Taiwanese ICT players can be regarded as an important catalyst in the introduction of brand new or further generations of ICT products to the global market. Taking notebook computers as an example, Taiwanese firms have served the top three brand marketers (HP, Dell and Apple) as major innovators and suppliers of the key components and parts needed and integrated hubs of production and logistics networks. Therefore, both parties, together with suppliers of components and parts have to work closely, right from the beginning, in order to develop and design different generations and varieties of notebook computers. Moreover, Apple’s success in iPhones was supported by R&D efforts by a number of Taiwanese ICT firms, as well as the deployment of production and logistics networks. Taking all these factors together, it can be argued that from the perspective of the ICT industry, Taiwan’s NIS is closely linked with the GIN led by the brand marketers.

Without denying its significance to the GIN, there are concerns that the Taiwanese ICT industry, particularly the computing/communications subsector, is subject to bottlenecks. First of all, the industry is facing an era of razor-thin profit. Secondly, the Taiwanese ICT industry is short of capabilities to define and create the dominant architecture design for new generations of ICT products, which may lock it into the trajectory of OEM/ODM manufacturing. Thirdly, due to its overconcentration in the ICT sector, especially its intermediate goods in terms of domestic production, Taiwan may become particularly vulnerable to the downturn of the global economy. This has proved to be the case during the recent global financial crisis.

To overcome these bottlenecks, the government has formulated several policies to facilitate the transformation of Taiwan's ICT industry. Firstly, the government is actively promoting the servitization of manufacturing in the manufacturing sector, particularly the ICT sector. Secondly, the government is also promoting new fields such as Cloud Computing and car electronics, with an view to facilitating the diversification of the ICT industry. With particular regard to Cloud Computing, the MOEA has reached agreements with a couple of MNCs to develop the technologies and applications needed, in cooperation with local universities and research institutes.

In addition, Taiwan's new policy as regards China includes governmental initiatives that are highly relevant to the transformation of Taiwan's ICT industry. Taiwan has to come to terms with the rise of China by realigning its industrial science and technology development and the relevant policy addressing the cross-strait issues. Set against the above backdrop, new initiatives such as cross-strait cooperation in industrial standards, the Building Bridges Project, ECFA and the deregulation of Chinese investment in Taiwan have been launched mainly from the Taiwan side and have met with some positive responses from China. For cross-strait cooperation in industrial standards, both sides have reached agreements to work together on the fields of TD-SCDMA, LCD, LED and solar cells. As far as Taiwan is concerned, cross-strait cooperation in industrial standards is meant to come to terms with the rise of China and promote cross-strait economic relationships beyond the current typical form of Taiwan-based firms' relocation of industrial value chain to China. If it is successful, some Taiwanese ICT firms may be able to get involved in the formation of Chinese industrial standards and/or dominant architecture design at the early stage.

5.2. The Years Ahead: Outlook for the Future

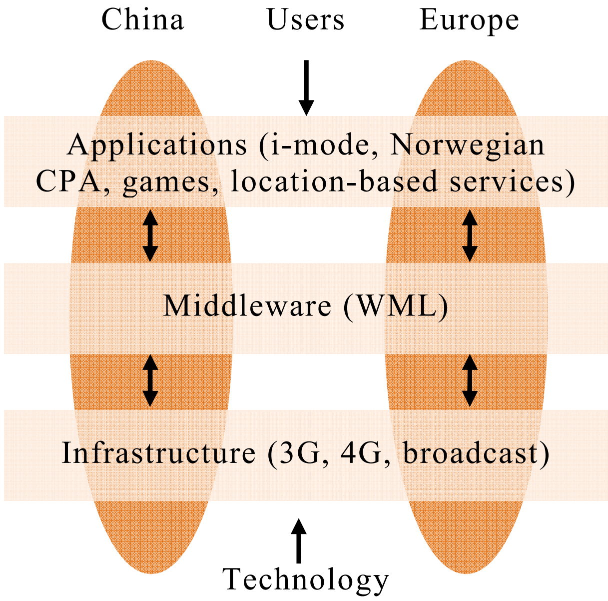
Although Taiwan's economic momentum is currently not as energetic as before, its ICT industry remains an important and powerful player in the global production and innovation network. This contrast has to do with the internationalization of Taiwan's ICT industry, particularly the computing/communications manufacturing sector, which in some cases may not be consistent with the developmental need of the domestic economy.

Taiwan's ICT-related industries, particularly DRAM and LCD, were severely affected by the Bullwhip effect, but the economic harm was mitigated by the so-called cross-strait "Peace Bonus" effect, which was facilitated by new initiatives such as cross-strait cooperation in industrial standards, the Building Bridges Project, ECFA, and the deregulation of Chinese investment in Taiwan launched mainly from the Taiwan side. Although these Taiwanese initiatives have met with some positive responses from China, it remains to be seen whether the Peace Bonus will improve Taiwan's long-term prospects. Despite positive signs of economic bounce-back on the global scale, the chances are that it will take longer for the developed world to get back on to a healthy economic track. Therefore, China, even though its projected economic growth rate was above 8% in 2009, is shifting its economic policy focus from FDI- and investment-driven export industrialisation to the promotion of domestic demand, industrial transformation, indigenous innovations and so on. With its current strengths, Taiwan's leading ICT players are called upon from the Chinese side to take advantage of the booming domestic market in China, which may involve the relocation of their production capacities and capabilities from Taiwan to China, as in the case of LCD sector. Given the fact that, in terms of domestic production and exports, Taiwan's ICT industry focuses on intermediate goods, the way in which Taiwan's economy can benefit from the ICT sector's tapping China`s domestic market remains an important issue on the policy agenda. Also, further dialogues are still needed before these efforts bear fruit in terms of promoting specific and genuine cross-strait cooperation at the industrial level.

The initiative to promote cross-strait cooperation in industrial standards has continued for several years. This effort coincides with widely-publicised strategies to promote indigenous innovation and industrial standards in China. A few areas have been identified as the priority themes for cross-strait cooperation in industrial standards, with mutual consensus to go beyond dialogues. However, compared to many other countries, cooperation between Taiwan and China in industrial technology is not unique, but somehow different. Referring to the three level model for standards and innovation in ICT proposed by the China-European Union Standards project (see Graph 29), the current focus of cross-strait cooperation in industrial standards lies mainly in production- and/or at application level, while for some of the advanced countries, such as the EU, Japan and even Korea, their cooperation with China tends to involve the architecture level (for example 4G). This difference is in part because Taiwan remains short of substantial influences on core technologies in some cases. However, as long as Taiwanese firms are involved in production- and/or application-related standards, they can still be instrumental in the introduction of brand new or further generations of ICT products to the global market.

On the other hand, there are issues to address that are key to cross-strait cooperation and competition in industrial science and technology and the policy. First of all, both sides need to set up delicate mechanisms and supporting measures in order to realise genuine cross-strait cooperation in industrial science and technology. This may involve issues to be solved at the different phases of the proposed ECFA. Secondly, Taiwan must strike a balance between cooperation with China and cooperating with the rest of the world. In some cases, cooperation between Taiwan and China may involve partners from other countries. Thirdly, Taiwan must also address cooperation with China at the sub-national level, going beyond simply Taiwan's FDI within China. The Program for Bridging Cross-Strait Industrial Cooperation tends to be sector-specific, but this is not the only way. One important feature of China is its sheer geographical size and, more importantly, substantial regional variations in economic development and innovation capacity. As regards the regional variations, Taiwan may in many cases need to go beyond the sector-specific framework, when it comes to cross-strait industrial cooperation. In other words, it could be cooperation with China at a sub-national level that means more and is more feasible for Taiwan. Fourthly, cross-strait cooperation with China must be accompanied by a strategy to promote Taiwan's leading players, especially taking into account the fact that some of the Chinese local industrial players have enjoyed international status and visibility. Related to this, it is important for Taiwan to keep a closer eye on the growing competition between the two sides because the Chinese government has formulated plans to consolidate key industries and to implement its “Going Global” policy.

Graph 29: Three Level Model for Standards and Innovation in ICT[26]



Source: adapted from http://www.china-eu-standards.org/details.htm, accessed on May 20, 2009.

In the light of the new economic situation across the Taiwan Strait, the term "Chaiwan" has been coined in Korea, which refers to the new partnership between China and Taiwan as a potential threat to some Korean firms. However, as far as Taiwan is concerned, such new initiatives as the ECFA and the Building Bridges Project are not meant for Taiwan and China only. From the perspective of public policy, these new initiatives serve to link up the "broken chain" between China and Taiwan in the global context. If they are successful, firms from other countries will not be forced to make a trade-off between China and Taiwan, if they want to explore the economic potential in the Greater China Area. As argued by Nobuyuki Idei, a former Chairman and CEO of Sony, the new economic situation across the Taiwan Strait may make Taiwan a valuable partner for Japanese firms to tap the Chinese market.[27]

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[26] According to the China-European Union Standards project, the rationale behind this model is the development of ICT to follows a well-established pattern: early activity focuses on the basic technology, then as the technology matures the focus shifts towards the development of applications and services. As this happens the focus of standardization activities evolves from basic technology towards middleware. At the application level product and service suppliers are able to exploit the standards created at the lower levels to produce distinctive and differentiated proprietary products (see http://www.china-eu-standards.org/details.htm).

[27] This is an unofficial translation of part of Nobuyuki Idei's speech in Taipei on the 8 December, 2009.

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Appendix: Taiwan's ICT Scoreboard: Top 20 Firms by Sales (2007)

Rank of Yr 2007	Company Name	Subsector	Turnover/Sales, EUR Yr 2007, Million, as of the End of Year 2007	Employee Yr 2007, Person	Products	Website
1	Hon Hai Precision	Computer manufacturing	25,814	5,318	Connectors, OEM/ODM for computers, notebook computers, printers projector, server; mobile phones, hand held devices and home entertainment equipment	www.foxconn.com
2	Quanta Computer	Computer manufacturing	15,301	3,466	OEM/ODM for notebook, PCs, smart phones, servers, digital TV, and automobile modules	http://www.quantatw.com
3	Asustek Computer	Computer manufacturing, computer components	12,324	8,885	Branding firm for PCs, notebook computers, digital home equipment, mobile phones, and accessories	http://www.asus.com.tw
4	AU Optronics Corp.	Optoelectronic materials, components & products	10,022	20,536	LCD TVs, monitors; notebooks, industrial display, and accessories	www.auo.com
5	Compal Electronics	Computer manufacturing	8,930	2,566	Notebook, ODM Service & Support	www.compal.com
6	Acer	Computers, peripherals & software wholesale	6,668	1,477	Branding firm notebooks, desktops, servers, and projectors	http://www.acer.com.tw/
7	Taiwan Semiconductor Manufacturing Co.	Semiconductor manufacturing	6,553	20,555	Semiconductor foundry and related services	Http://www.tsmc.com
8	Chi Mei Optoelectronics Corporation	Optoelectronic materials, components & products	6,265	17,333	LCD TV panels, notebook panels, and special-application panels	www.cmo.com.tw

Rank of Yr 2007	Company Name	Subsector	Turnover/Sales, EUR Yr 2007, Million, as of the End of Year 2007	Employee Yr 2007, Person	Products	Website
9	Wistron	Computer manufacturing	5,784	3,896	OEM/ODM for notebook computers, desktop systems, servers, and storage systems, and after-sales service support function for ICT products	www.wistron.com
10	Inventec	Computer manufacturing	4,997	3,753	Personal computing, mobile communication, consumer electronics	http://www.inventec.com.tw
11	Lite-on Technology	Computer manufacturing, computer peripherals, optoelectronic components & products	3,471	2,335	Power supply, computer peripherals, PDAs, PNDs and accessories	http://www.liteon.com/
12	Innolux Display	Optoelectronic materials, components & products	3,259	3,110	TFT-LCD panel modules mainly applied to the monitor product of desk type monitor, and the display unit products of medium and small-sizes for cellular phone, portable DVD player, etc,.	http://www.innolux.com/
13	Chunghwa Picture Tubes	Electronic tubes; optoelectronic materials, components & products	3,007	8,888	TFT-LCD Products, CRT products	www.cptt.com.tw
14	Qisda	Computer manufacturing	2,554	1,899	LCD monitors, projectors, computer peripherals, mobile phones & wireless module, infotainment solutions	http://www.qisda.com.tw/
15	HTC	Handset manufacturing	2,477	5,569	Touch phones, PDA phones, smart phones, mobile computers	http://www.htc.com

Rank of Yr 2007	Company Name	Subsector	Turnover/Sales, EUR Yr 2007, Million, as of the End of Year 2007	Employee Yr 2007, Person	Products	Website
16	United Microelectronics Corp.	Semiconductor manufacturing	2,231	13,720	Semiconductor foundry solutions	http://www.umc.com/
17	Foxconn Technology	Optoelectronic materials, components & products	1,967	205	OEM/ODM for portable computer enclosure, mobile phone enclosure, 3C products, and consumer electronics products	www.foxconntech.com.tw
18	Micro-Star International Co.	Computer components	1,893	2,170	PCs, motherboards, graphics card, notebooks, consumer electronics, communication, barebones, Servers, industrial computing	http://www.msi.com.tw
19	Elitegroup Computer Systems Co.	Computer components	1,745	1,311	Motherboards, graphics cards, notebooks, servers, portable media players, industrial motherboard	http://www.ecs.com.tw
20	Mitac International	Computer manufacturing	1,715	1,468	PCs, motherboards, barebones, workstations & servers, wireless communications products, portable navigation devices, handheld computers, and technical support and after-sales service for the above products.	www.mitac.com

Note: I EUR= 47.8652 NTD, listed exchange rate in 2007/12/31, Central Bank of the Republic of China (Taiwan); retrieved from http://www.cbc.gov.tw/lp.asp?ctNode=383&CtUnit=129&BaseDSD=7&mp=1(2009/2/13)

Note: The 12th and 19th are not included in the earlier version of top20 list(2009/02/13), that means they were out of top20 in year 2005.

Source: 1. Top 5000 in 2008: The Largest Corporations in Taiwan. China Credit Information Service, Ltd.

2. Compiled by CIER.

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Title: Trends in Public and Private Investments in ICT R&D in Taiwan

Author: Dr. Shin-Horng Chen, Dr. Pei-Chang Wen and Dr. Meng-chun Liu

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Technical Note

Abstract

The Information Society Unit of the IPTS (European Commission) has been investigating the Information and Communication Technologies (ICT) sector and ICT R&D in Asia for several years. This research exercise led to three reports, written by national experts, on China, India and Taiwan, each one including a dataset and a technical annex. This report covers Taiwan.

The report describes the ICT sector, gives a company level assessment, analyses the ICT R&D strategies, and assesses the Taiwanese innovation model.

Ever since the 1980s, the ICT industry has been the paramount engine of economic growth in Taiwan, with many Taiwanese-made ICT hardware products enjoying a significant global market share. Both foreign direct investment and technology transfer from the advanced countries, particularly the USA and Japan, have triggered local firms' entry into the different subsectors over time, from the computing/communications manufacturing, Integrated Circuits and more recently to Liquid Crystal Display subsectors. However, local firms have also managed to establish strong technological and innovation capabilities through internal R&D, technology transfer from local research institutes, and the establishment of science parks. Behind this development are the well-regarded production and design capabilities of the Taiwanese ICT producers, which in turn have made Taiwan a major source of contract work for internationally prominent ICT firms.