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Global Production Networks and Host-Site Industrial Upgrading: The Case of the Semiconductor Industry in Thailand*

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Abstract: *Although Thailand's electronics industry has been considered as one of strategic sectors, the evidence in this article shows that it is dominated by midstream and downstream activities. Despite accounting for a quarter of electronics exports, semiconductors manufacturing is confined to low value added activities. The lack of industrial policy has restricted technological upgrading in the industry. Upgrading efforts made by both public and private initiatives have so far failed. The case studies show that firms in Thailand must acquire and develop technological capabilities to stimulate the industry's transformation from low to high value added activities.*

***Keywords*:** intra-industry trade, semiconductors; technological capabilities, Thailand; upstream industry

JEL Classification: L62, L22, L14, O31

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1. Introduction

Semiconductors share a small portion of global electronics industry sales, mainly from integrated circuits (ICs) or "die" or "chip" and discrete devices. An increasing technological domination from a few global "Chip Maker" and a requirement of grand scale capital for new investment in the sector can be seen as the industrial key characteristics. Semiconductors are crucial to all electronic products and to a knowledge-based economy. There are very important parts in computers, consumer electronics and telecommunication equipment including wireless networks and handsets, industrial machinery, transportation equipment, military hardware and so forth.

In Southeast Asia, FDI has also played a leading role through the relocation of the multinational corporations (MNCs), which resonates a high degree of intra-regional value chain across the region (Rasiah, 2003, 2010). Thailand is one of major manufacturing bases of the global electronics industry. The sector is among the most important and strategic export-oriented industry. The MNCs dominate the assembly activity with an extensive control over supply chain of parts and components. Central and Eastern regions of Thailand are among the most favourable locations for the industry, following by north eastern and northern regions. Semiconductor is one of important sub-sectors in the Thai electronics industry.

This study aims to examine the semiconductor industry in Thailand, where sectoral challenges being laying down a new foundation of the intra-regional trade, particularly on the upstream industry. It aims at contributing to the more understanding of the global production networks, firms' technology strategies and host-site industrial upgrading of a developing country relying heavily on foreign direct investment (FDI).

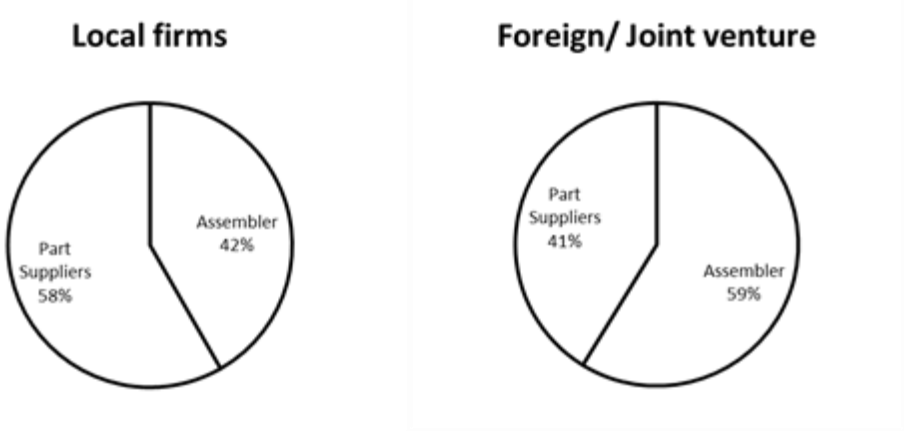
The study utilizes primary and secondary data. Primary data was collected from three major sources, including Thailand's Electrical and Electronics (EEI), National Electronics and Computer Technology Center (NECTEC), and Thai Federation of Industry (FTI) database. Subsequently, Import-Export database between 1999 and 2011 of Thai Ministry of Commerce and UNCOMTRADE data base between 1992 and 2011 were used to analyse the intra-industry trade and products for inter-industry trade (one-way trade) and intra-industry trade (IIT) of Thai ICs and Electronic Components. Finally, to understand firms' technology strategies and learning processes, we interviewed five companies with different characteristics, representing different types of firms in the industry.

2. Semiconductor Industry: An Overview and the Role of Host-site Institutions in Technological Upgrading

Thailand has joined the global value chain of electronics industry in the 1970s, at the same time with Malaysia and a decade after Singapore (Hobday and Rush, 2007). Between the 1970s and 1980s, Thailand became another assembly hub in Southeast Asia for diodes and capacitors (Chairatana, 1997). It was very much concentrated on downstream labour-intensive assembling and packaging activities. Nonetheless, Thai semiconductor industry has been overshadowed by the successful development of Thai hard disk drive (HDD) industry and more advanced semiconductor industry in Malaysia.

At present, semiconductor industry in Thailand accounts for one quarter of the whole electrical and electronics (E&E) export. Out of 2,034 firms in Thai electronic industry, there are around 3 percent of firms in semiconductor-related activities (EEI, 2012). Majority of firms are small and medium sized enterprises with a substantial representation of MNCs in an assembling domain (see Figure 1).

Figure 1: Structure of Thai Electrical and Electronic Industry in 2012 (%)



Source: Thai Electrical and Electronics Institute.

In the late 1980s, local Thai semiconductor enterprises with support from public research and technology organization (RTO) tried to climb a technological ladder from simple assembling and packaging to process engineering development. Thailand has started its research and development (R&D) activity on micro-electronics in 1989 by joining the ASEAN - Australia cooperation project. Some Very Large Scale Integration (VLSI) have been designed in-house and sent for fabrication in Australia during the program. Micro-

electronic industrial infrastructure was loosely established, which can be seen from evolution of three key host-site intermediary agents as follow;

2.1. National Electronics and Computer Technology Center

Lacking in active strategies and commitment at the national policy level on industrialization (Rasiah, 2009), as the only national RTO in electronics, the National Electronics and Computer Technology Center (NECTEC) began to support Thai microelectronics through promotion of IC/VLSI design and wafer fabrication since the early 1990s. Both activities were NECTEC's own imitative and small. Then, the cabinet approved an establishment of a wafer fabrication line for Complementary Metal Oxide Semiconductor (CMOS) process technology below 1 micron with the capacity of 500 six inches wafers/month in 1995. Initially, the government planned to partner with a local semiconductor enterprise by investing USD 12 Million in three years for establishing Thai Microelectronic Center (TMEC) with a donation of six million USD from locally owned firm, the Alphatec Group. As a result, two wafer fabrication ventures were initiated, namely Submicron Technology Co., Ltd. and Alpha-TI Semiconductor Co., Ltd. However, both projects were heavily affected from the 1997 Asian financial crisis. An investor could not secure sufficient funds, and later the projects were cancelled. The factories built were empty as partially installed machinery was out of order. Therefore, the machinery was confiscated by creditors. Submicron Technology's asset was acquired by NECTEC and transformed into the facility for TMEC, completed in after the 2000, instead (See details below). The failure to establish the first private-owned wafer fabrication facility in Thailand can be seen as a major landmark in the evolution of Thai semiconductor industry from the 1990s (Chairatana, 1997).

Comparing with wafer fabrication, IC/VLSI design area is not highly capital-intensive. Underlying technology is still growing. There was a worldwide shortage of VLSI designers. Therefore, this was a business opportunity. Building up in-house IC design capability became a prime innovation strategy of NECTEC. NECTEC initiated several new activities targeting, IC packaging industries, hard disk drive industries, system houses, and design houses by establishing Microelectronics Forum and graduate programs, IC Design Network, and supporting building technological capability of local private design houses.

2.2. Thailand's Electrical and Electronics Institute

In 1998, Thailand's Electrical and Electronics Institute (EEI) was established under Ministry of Industry with the aims to become a main organization in enhancing the country's potential and capability to compete in the global market. Its objectives are 1) to encourage and promote the utilization of local materials and parts for the continuous value-added production of electrical and electronics goods, 2) to leverage the international standards for improving quality of Thai electrical and electronics products and their exports, and 3) to be a centre in collecting, analysing, conducting research and updating information on Electrical and Electronics industry (E&E) in the aspects of production, marketing, and international trade agreement. This can be seen that Thai policy toward the industry is prioritized on downstream assembly and development of supply chains for electrical machinery and home appliances. Interestingly unlike Economic Development Board of Singapore and Penang Skill Development Centre of Malaysia, the institute also has not really acted as an intermediary facilitating knowledge flow and capability building process between multinationals and local suppliers.

2.3. Thailand Embedded System Association

In 2001, Thailand Embedded Systems Association (TESA) was founded by group of academia and local private industrialist as a forum for developers and technology users in the field of embedded computing technology. TESA organizes the Embedded Systems Forum as a networking space for collaboration to create opportunities and strengthen the competencies of members, to promote innovation in developing embedding systems technologies in Thailand, to develop human resources in embedded systems technology, to support the development of government technology policy related to embedded systems, and to create a positive investment environment for expanding industry. TESA members are over 30 corporates and 30 technology solution providers and customers. They also include more than 300 individual technology developers, professors, and students. Partners of TESA are 13 universities in Thailand, key research & technology organizations (RTOs), and big local and international corporates. TESA performed intermediary roles. It developed eight technology roadmaps related to the embedded systems industry for three ministries, provided testing services and certified electronic products, and matched new start-up s with investors.

Attempts to go upstream continued. In August 2004, Board of Investment (BOI) revised conditions and incentives to stimulate interests in wafer fabrication investment by exempting

import tariffs on machinery without time limit and exempting corporate income tax for eight years regardless of location and with no investment cap. Subjected to approval, existing investment projects could also import machinery and equipment with duty exemption in order to enhance efficiency and technological capabilities. IC enterprises were incentivized to expand its activities to cover wafer processing.

With the above attempts, the sector still lags behind other countries in designing and testing of integrated circuit (IC), transistor, capacitor, resistor, diode, and so on. Main inputs like wafer and bonding wire are mainly imported from abroad while some local inputs were lead frame. For example, in 2003, Thailand mainly exported semiconductor products from downstream segments. They were composed of export of ICs worth USD 6.3 billion and export of diode, transistor and other semiconductor parts worth around USD 2 billion (See Table 1).

Table 1: Import Source of Raw Materials for Transistor Production, Thailand, 2003

Parts/Raw materials	Import proportions (%)	Markets
Lead frame	30	Singapore, Japan, Philippines
Silicon wafer chip	100	Japan
Bonding wire	100	Singapore, Malaysia
Epoxy resin	75	Singapore, Malaysia

Source: Thai Electrical and Electronics Institute

During 2002-2006, total export of electrical and electronic products doubled. In comparison, imports of electronic components and semiconductor slowly increased (See Table 2). Thailand imports diodes, transistors, and semiconductors mainly from Japan, followed by China, Singapore, USA, and Malaysia, respectively.

Table 2: Semiconductors Imports and E&D Exports, Thailand, 2002 – 2006

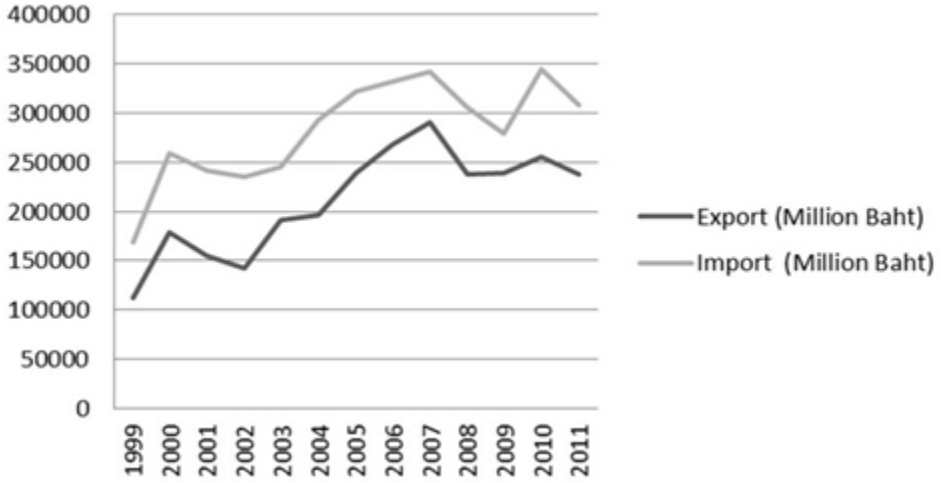
	2002	2003	2004	2005	2006
Imports of Diodes, transistors and semiconductors (Million Baht)	28,720	29,892	33,830	33,222	33,457
E&E Exports (Million Baht)	141,912	191,540	196,444	238,454	267,598

Source: Thai Electrical and Electronics Institute

3. Intra-Industry Trade and Products

Between 1999 and 2011, the exports of semiconductor from Thailand tremendously grew from USD 3 to USD 7 billion. The sector contributed around 2.5-3.5 percent of GDP, while it had a trade deficit (See Figure 2)

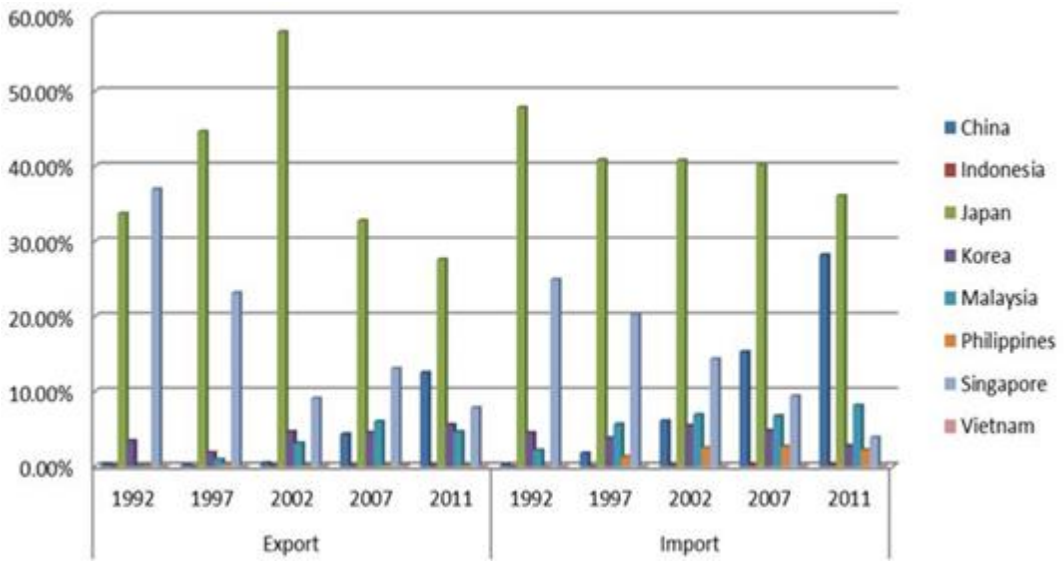
Figure 2: Electronics Component Trade, Thailand, 1999-2011



Source: Ministry of Commerce, Thailand and Bank of Thailand

The most important market for import and export of Thai semiconductor was Japan. It accounted for around 35-55 percent of total exports. Singapore was number two in 1992, with 35 percent of total export, but her importance continuously declined. China, Korea and Malaysia have increasingly replacing Singapore (See Figure 3).

Figure 3: Percentage of Intra-industry Trade in Electronics Components between hailand and Selected Economies, 19992-2011



Source: UN Comtrade, Commodity code 8541.

The value of exports and imports of integrated circuits (ICs) and electronic components between Thailand and global partners between 1992 and 2011 highly depended on manufacturing for re-export with a relatively small margin for a domestic sale (See Table 3).

Table 3: Trade Indicators, Electronic Components, Thailand, 1992-2011

	Export	Import	G-L Index	Inter trade
1992	1332,6	1899,5	0,82	0,18
1993	1709,2	2460,7	0,82	0,18
1994	2244	3493,3	0,78	0,22
1995	2935	4993,6	0,74	0,26
1996	3218,1	5558,4	0,73	0,27
1997	3380,6	5451,7	0,77	0,23
1998	3169,2	4910,4	0,78	0,22
1999	4031,1	5928,1	0,81	0,19
2000	5876,9	8365,6	0,83	0,17
2001	4699,7	6791,6	0,82	0,18
2002	5090,4	6979,3	0,84	0,16
2003	6307,3	7565,5	0,91	0,09
2004	6321,7	9080,6	0,82	0,18
2005	6538,2	9520,5	0,81	0,19
2006	8310,5	10130,4	0,90	0,10

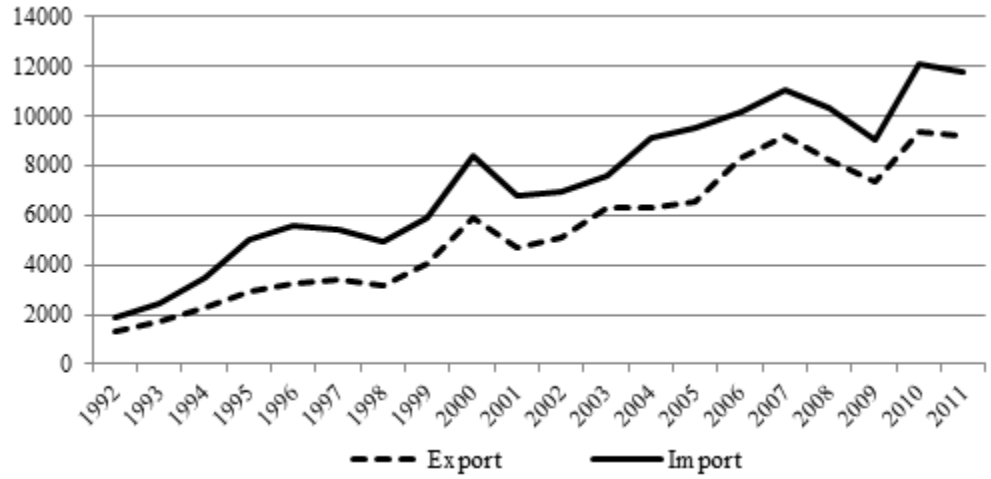
2007	9237,8	11061,4	0,91	0,09
2008	8210,3	10350,4	0,88	0,12
2009	7383	9012,3	0,90	0,10
2010	9383,8	12056,4	0,88	0,12
2011	9223,6	11778,2	0,88	0,12

Source: WTO (2013); authors' calculations.

Exports have been exceeded by import because of weak capabilities in the upstream industry as mentioned earlier (See Figure 4). It is noteworthy that a growth pattern for this industry has been mainly affected by the global demand, which makes it very vulnerable comparing with other leading sectors such as automotive or food processing ones. During 1994-2000, trade on integrated circuits and electronic components were on the rise, because of foreign investment and relocation of production base. But in 2001 and during 2008-2009, the global demand, especially in America and Japan, were in decline, and, hence, the growth of the Thai industry decreased.

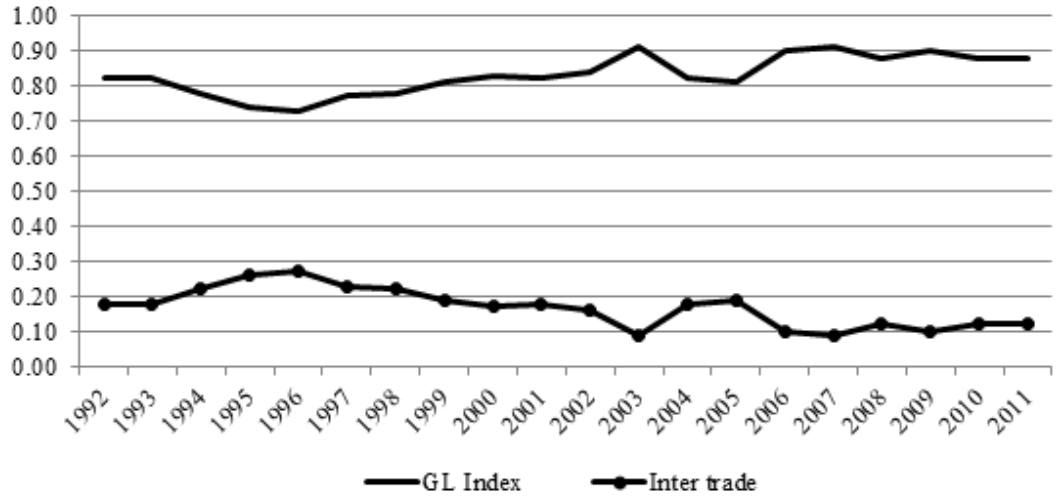
Figure 5 shows the rising trend of the G-L index during 1992 to 2011, indicating that Thailand's ICs and components industry has been increasingly linked with other countries.

Figure 4: Export and Import of Electronic Components between Thailand and Global Partners, 1992-2011



Source: WTO (2013); authors calculations.

Figure 5: G-L Index and Inter-industry trade in Electronic Components, Thailand, 1992-2011



Source: WTO (2013); Authors calculations

Table 4 shows the G-L index and intra-industry trade in semiconductor industry between Thailand and selected countries. Since 1997, Japan, Korea and Singapore have been key trading partners with Thailand. It indicates that Thailand has been a significant base in the production networks of Japan, Korea and Singapore. The intra-industry trade with Malaysia was also high.

Table 4*:* Intra-industry trade, Semiconductor industry, Thailand, 1992-2011

	1992		1997		2002		2007		2011	
	G-L index	Intra- trade	G-L index	Intra-trade	G-L index	Intra- trade	G-L index	Intra- trade	G-L index	Intra- trade
China	0,91	0,09	0,27	0,73	0,29	0,71	0,48	0,52	0,48	0,52
Indonesia	n/a	n/a	n/a	n/a	0,87	0,13	0,59	0,41	0,45	0,55
Japan	0,82	0,18	0,78	0,22	0,49	0,51	0,95	0,05	0,71	0,29
Korea	0,85	0,15	0,82	0,18	0,70	0,30	0,97	0,03	0,82	0,18
Malaysia	0,07	0,93	0,39	0,61	0,99	0,01	1,00	0,00	0,58	0,42
Philippines	n/a	n/a	0,54	0,46	0,22	0,78	0,16	0,84	0,07	0,93
Singapore	0,82	0,18	0,76	0,24	0,84	0,16	0,78	0,22	0,82	0,18
Vietnam	n/a	n/a	n/a	n/a	0,15	0,85	0,20	0,80	n/a	n/a

Source: Author's own calculation based on UN Comtrade database, Commodity code 8541.

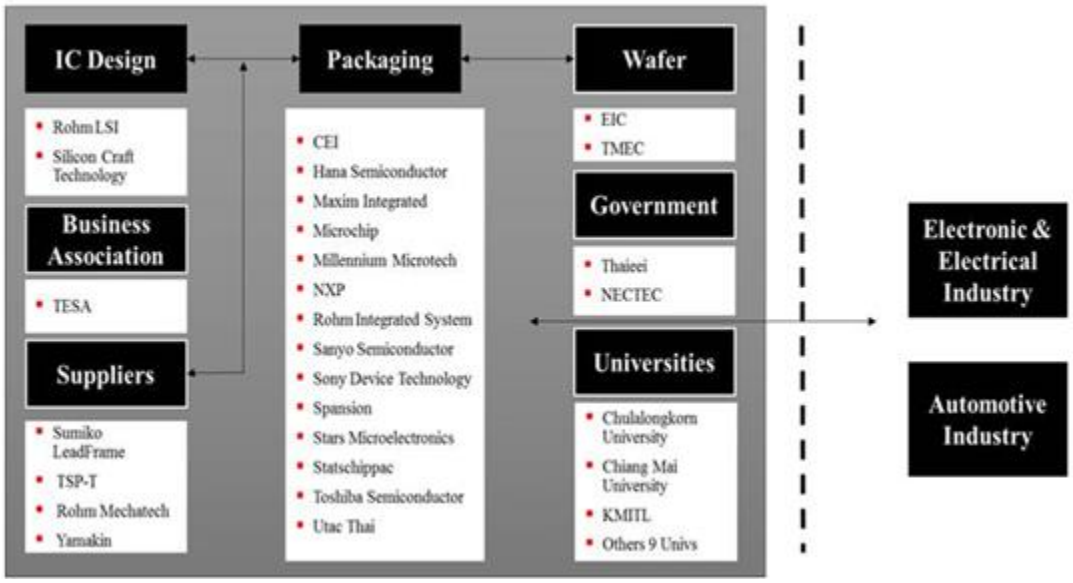
4. Case Studies

Although Thai semiconductor sector has faced a difficulty in upgrading from downstream to upstream industry, there were a few significant, albeit not very successful, public and private attempts to upgrade the industry. These attempts can be seen as lessons learnt for other developing countries aiming to technologically upgrade their industries.

Integrated Circuit (IC) packaging plays a crucial role in Thai semiconductor industry. Most of semiconductor firms in Thailand have been involved with IC-packaging. The supply chain of this specific group is well-established. The MNCs' subsidiaries in Thailand achieved substantial technical acquisition and upgrading for the last two decades, while R&D activities for new product or process innovation still mainly conducted outside the country (Hobday and Rush 2007). High performance semiconductor packaging and investment on automation were increasingly utilized as it offered higher efficiency and required less labour. Research and innovation activities among Thai-own large corporations have also increased, particularly on IC and appliance designs.

IC-design has slowly increased partly because the relocation to the country of foreign-specialized firms and demand from the HDD industry at home. There are three universities with a strong research capability in this area – Chulalongkorn University (CU) and King Mongkut's Institute of Technology Ladkrabang (KMITL) in Bangkok, and Chiang Mai University (CMU) in Chiang Mai, including other 9 universities. Figure 6 maps out the structure of Thai semiconductor industry.

Figure 6: Structure of the Semiconductor Industry, Thailand, 2013



Note: Authors' compilation.

In order to understand an evolution of semiconductor technological and innovation capabilities, linkages, and industrial network, we examined five firms with different types of ownership and specialization. They are three IC packaging companies (a subsidiary of foreign MNC, a Thai-based MNC, and a local firm), one state-owned wafer fabrication research organization, and a locally owned IC design enterprise (See Table 5).

Table 5: General Characteristics of Case-study Firms

	Type	Year Established	Ownership	Number of Employees (1)	Main Products & Services
Hana Semiconductor Ayutthaya (HM)	EMS/ODM	1978	Thai based PLC(2)	3,300	Microelectronics, semiconductor and LCOS(3)
Toshiba Semiconductor Thailand (TST)	Subsidiary	1990	FDI	1,400	Discrete semiconductors (small signal devices, photo couplers)
Stars Microelectronics (SMT)	EMS/OEM	1995	Thai PLC	1,450	MMA(4), IC packaging
Thai Microelectronics Center (TMEC)	Wafer Fabrication	1996	State owned	80	0.5 micron ASIC(5), IC/VLSI design and testing

Silicon Craft Technology (SIC)	IC Design	2002	Local	65	ASICs for RFID[6], IC design,

Note: (1) As July 2013 / (2) Public Company Limited / (3) Liquid Crystal on Silicon / (4) Microelectronics Module Assembly / (5) Application-Specific Integrated Circuit (6) Radio Frequency Identification Device

4.1. Hana Microelectronics

Hana Microelectronics (HM) is a Thailand-based multinational electronic manufacturing services corporation and one of 100 largest companies listed in the Thai stock market. It is specialized in mems, sensors, clear/optical packages, semiconductor IC assembly and testing. At present it has five facilities in 1) Bangkok, 2) Lamphun (in Northern Thailand near Chiang Mai), 3) Ayutthaya (15 miles north of the Don Muang International Airport), 4) JiaXing, China, and 5) US (occupying over 1,000,000 square foot of manufacturing space with approximately 11,000 employees). Hana also has a significant stake in Advanced Interconnect Technologies Ltd which has IC assembly and test operations in Batam Indonesia, Hong Kong, and California.

HM was established in 1978 as a small electronic assembly house and listed on the Securities Exchange of Thailand in February 1993. Hana is capable of providing a wide scope of assembly processes serving a diverse range of electronic industries which includes semiconductor, microelectronics, and microdisplay.

HM (Ayutthaya) is a contract manufacturer as well as a Hana's subsidiary providing EMS (electronics manufacturing services) without its own products. Its contract manufacturing function includes operating as original design manufacturer (ODM) and original equipment manufacturer (OEM). The company focuses on producing tiny and small IC packages in bulk that its facility being capable of ranging from smartphone to automotive (C. Disyamal, personal communication, July 24, 2013). Total production capacity for IC packaging is around 20 million units per day and 80 percent of them are tested here.

HM's core competency is in its process i.e., assembling and testing services based on Total Quality Excellence (TQE) and Quality Control Circle (QCC). Hana's employees apply the so-called 'FORCES approach': Follow written specification always; Own and be Responsible for my work; Care for my work; Exceed customers'

expectation; and Stop production when any abnormality happens (P. Naradilok, personal communication, July 24, 2013).

After being a listed company, HM acquired several global and demanding customers. This is significant 'learning event' that helps the company to considerably upgrade its technological capability through on-going interaction with these global customers. In this process, HM needs to consistently solve technological problems concerning process engineering and design raised by customer. R&D unit initially set-up as a not-so-important function became indispensable driver to achieve this goal. As a result, a profound foundation has been laid for future transformation of the company from leading regional OEM into capable own designed manufacturer (ODM). As an ODM, Hana can deliver state-of-the-art products to customers. In the case of a customer demanding standard packages, the orders will be delivered easily. Besides standard packages, its R&D department and others worked closely with customers to design and develop customized package solutions. Hana's new and innovative products are driven by customer requirements. It receives ideas from customers and provides design or co-design for products and production processes to ensure that they are price competitive and marketed at the right time.

It should be noted that Hana's upgrading to an ODM was pressured by an external event. In 2011, Thailand experienced mega flood, HM's Headquarters and main factory at Ayutthaya were under water for three months. Hana (Ayutthaya) had to cut down obsolete standard packages that had been in its production line for too long and were no longer in demand in high volume (N. Charusabha, personal communication, July 24, 2013). This was a major blow to the company. However, afterward, it turned out to be blessing in disguise as HANA decided to shift to higher value added activities beyond standard production such as design of cost efficient small and customized IC packages (See Table 6).

Table 6: Breakdown of HM's products, 2013

	Standard packages	Customer-specific	Innovative
Pre-2011 megaflood	60%	20-30%	10%
Post-2011 megaflood	50% (High-volume runners remained)	20-30%	20%

Source: N. Charusabha, personal communication, July 24, 2013

HM maintains its backward linkage with suppliers for materials and equipment. At times they are required to improve suppliers' capabilities to make sure that they can meet Hana's requirements for a new product. In terms of forward linkage, they often cooperate with customers to design and develop custom packages to address specific needs. The cooperation network in semiconductor industry is difficult to form compared to the hard disk drive industry due to IC is only a component, not a complete product composing of many components like HDD and the market of EMS and subcontractor is highly competitive in terms of production process and costs. Hana finds that universities mostly do basic research and not applied one – thus the cooperation with the education institutions is very limited. Meanwhile, the recruitment of personnel mainly comes from science and technology specialized universities like King Mongkut's Institute of Technology North Bangkok (KMITNB) and King Mongkut's Institute of Technology Ladkrabang (KMITL). Hana has to provide intensive on-the-job training for the new recruits.

4.2. Toshiba Semiconductor (Thailand)

Established in 1990, Toshiba Semiconductor (Thailand) (TST) Co., Ltd. is a Toshiba's 100 percent owned subsidiary. TST carries out back-end processes– assembly and packaging–for small signal devices and photocouplers. Small signal devices control current and voltage in digital consumer products, a product segment being expected to grow in coming years, with a primary focus on smart phones and tablets PCs. Photocouplers are used widely in industrial products, such as inverters, and are also expected to see strong demand growth.

The company consider itself as an assembler with main production involving both front-end process (die attach process, wire bonding process, die overcoat) and back-end process (molding, marking, deflash and lead finish). Gross sales increased

continuously from 2000 to 2011. Cost of gross inputs was 70-80 percent of sales prices and proportion of local content use was 30 percent in 2012. Toshiba has total 1,600 employees with 3 percent being managers, 34 percent engineers and technicians and 62.5 percent labourers. All of its products are exported to Toshiba's subsidiary in Singapore, a regional sale office. Average lead time for export is 10-30 days. They imported 60-70 percent of inputs from Japan and the remaining is sourced locally. Its main suppliers in Thailand are also Japanese firms such as Panasonic (Ayutthaya), Mitsutomo (Ayutthaya) and Ishizaki. Engaging in global electrical and electronics manufacturer networks were considered as a significant factor for the firm's technology upgrading.

Like HM, the 2011 flooding completely inundated TST's manufacturing facilities, resulting in a forced suspension of operations. As TST made every effort to recover operations, Toshiba responded by transferring operations to its production facilities in Japan and Malaysia and making use of outsourcing. In April 2012, Toshiba Corporation announced that it had a plan to rebuild its semiconductor manufacturing operations in Thailand by relocating TST to a new manufacturing facility located in Prachinburi, approximately 140km northeast of Bangkok.

Toshiba Group is promoting a revitalization of its discrete device business aimed at boosting efficiency and profitability. Measures deployed to date include transitioning to larger wafers and higher output in the front-end process, and accelerating the overseas transfer of the back-end process. Construction of the new TST facility will improve cost competitiveness in the back-end process, strengthen the bottom line and contribute to the overall strength of the discrete business unit.

TST's core competency is its standardized production process, requirements, technology transfer as well as financial support from its parent company in Japan. It uses ISO 9000, ISO 14000 and OHSAS 18001 for quality control system; TPM, QCC and 5S for domestic activities and MRP and Oracle for inventory control system. Training expenditures for employees were accounted for 2 percent of total payroll. Each employee received around 24 hours of training every year. TST engages in incremental innovation activities by adapting machinery and equipment, process layout, inventory and quality control systems. The firm considered its production machinery's quality as intermediate. For the last 6 years, they have developed more

than 10 new-to-the-firm products by obtaining technologies from its parent company in Japan.

4.3. Stars Microelectronics (Thailand)

Stars Microelectronics Thailand (SMT) is a locally owned original equipment manufacturer (OEM) in computer, electronic equipment, automobile, communications, safety equipment, and entertainment businesses. It is also a subcontractor and an electronics product designer. Co-founders were an investor with a background in rice milling industry and a university professor from industrial engineering discipline. The company headquarter is located in Bangpa In Industrial Estate, Ayutthaya, Thailand with sale offices in Japan Germany, USA, and Taiwan.

SMT was founded in 1995 and earned a public company status in 2004, prior to be listed in the Stock Exchange of Thailand (SET) in 2009. It is among the first companies listed on to enjoy privileges of free trade zone granted by the Board of Investment of Thailand (BOI). The firm has a registered capital of 730 million Baht (21 million US dollars). SMT is actively engaged in an upstream mass production of microelectronics module assembly (MMA) and Integrated Circuit (IC) packaging with the factory space of 25,500 square meters. The company is currently expanding its production capacity of MMA to 100 million units per year and IC Packaging to 1.2 billion units per annum with a total of 1,450 employees, including engineering staff of more than 120 persons.

SMT's core competency is in advanced EMS for MMA, IC packaging and testing based on on-site and solution-based practice provided by its local engineering teams. Another core factor is operation space management that provides secured and dedicated space where clients' intellectual properties and design are not exposed. Executives of SMT recognize the importance of innovation, but it is not considered as priority for leveraging of firm's competitiveness. Process innovation can be observed from an investment in new machines and technologies. However, once a large amount of capital is invested in a machine or an assembly line, it limits SMT production capability as one machine can only produce a certain range of products, and not the others. Therefore, process innovation is more common in this context in a bid to improve production processes, production controls and troubleshooting disciplines. In

contrast, product innovation is less evident due to limited nature of EMS or contract manufacturers i.e., producing by orders. Also its production capability is constrained by path-dependence of invested machines. Its influence over product modification is very limited and often found at latter stages in a production line.

External sources of innovation are from suppliers and clients. SMT often requests machine specifications from machine suppliers. It also has a continuous cooperation with its machine suppliers through communication and technical support provided by their sale representatives and research teams. One example is the case of developing new wire bonder. Engineers from production line provided feedback that old wire bonder had a short life span and required the machine operator to stop the machine and change the wire bonder. With the new wire bonder, the production is higher and the cost is reduced.

On the opposite, though SMT co-located in the same Free Trade Zone with its customers in hard disk drive industry, co-operation is rare. SMT had to increase capabilities by its own to meeting increasing demands of these customers. However, with a new business opportunity like a rise in demand for ultra-high Radio Frequency Identification (RFID) chips, SMT was given a chance to co-design of new products. This allows SMT to co-operate with its clients through its on-site skill of manufacturing and process engineering. The company also learned to integrate new machineries by order of clients into its manufacturing process. This is a major learning event.

Collaboration with local research and technology organizations (RTO) and universities was very limited. Even, SMT had some collaboration with NECTEC through equipment sharing and project testing, NECTEC could only meet a few requirements from the company such as providing training its new engineers on clean room technology by TMEC – a unit of NECTEC. Likewise, research capability of universities does not match with the firms' advanced technology.

4.4. Thai Microelectronics Center

Thai Microelectronics Center (TMEC) was established in 1996 as a unit under a public research organization, NECTEC. It aims to enhance production efficiency and development of Microelectronics prototypes being practically adopted by various

industries, and to support domestic IC design industry. By cooperating with nationwide universities and firms, TMEC has acted as a training centre for both process and design engineers. As a result, its current activities comprise research in microelectronics, product development (sensors and transistor), services (IC design, advanced packaging technology and testing), and education. Currently, TMEC has 80 Master and PhD researchers and engineers.

TMEC possesses a pilot-level wafer fabrication plant. It is now mainly used as a training facility for private firms' engineers and technicians. In the future, TMEC aims to proceed with small-scale wafer fabrication for sensor machines to serve domestic niche market. This can be seen as a small attempt by a Thai public agency to revitalize the upstream semiconductor industry (A. Poyai, personal communication, February 14, 2013).

On technological learning, during 1997 and 2000, TMEC sent its engineers and technicians to Interuniversity Microelectronics Center of Belgium (IMEC) for training of wafer fabrication techniques and management. These include transfer basic process technology and necessary consultancy from IMEC.

For human resource development, TMEC has worked with more than ten major universities to develop a large pool of new designers supporting the rise of IC/VLSI design industry in Thailand. For example, in 1996, TMEC supported King Mongkut's Institute of Technology Ladkrabang (KMITL) with a grant of USD1 Million to launch a Multi Project Chip (MPC) program to upgrade the microelectronics facilities from 20 micron process to 5 micron CMOS process. Also, in 2000, TMEC and several universities launched an International Master's Program in Microelectronics with special focuses on design aspects, particularly for specific applications, IC packaging and storage technology. The program aimed to supply skilled human resources, particularly for the semiconductor industry and universities in Thailand and the rest of Asia.

4.5. Silicon Craft Technology

Silicon Craft Technology (SIC) was a startup established in 2002 by five Thai co-founders with engineering and IC design backgrounds. SIC is one of leading Thai knowledge-intensive business enterprises that value innovation and intelligence as the

driver of growth. It aims to deliver high quality of products compatible with the world's standard and regulations. The firm was the prime mover in an integrated-circuit (IC) design in Thailand. It had an ambition to make itself a showcase of local technopreneurship encouraging locals into the IC design business.

Managing Director and Co-Founder, Mr. Manop Thamsirianunt, used to work as analogy design engineer and IC design manager for semiconductor firms in Silicon Valley. Through a reverse brain drain scheme, he returned to Thailand in 2001 and became the head of Thailand IC Design Incubator (TIDI), a unit of the National Electronics and Computer Technology Centre (NECTEC). Some of other co-founders had doctoral degrees in engineering and university professorship.

SIC is in a business ranging from state-of-the-art, customized and standard microchips design for RFID applications. Core competence of SIC is in its experience and expertise in design and development of world-class foundry semiconductor manufactures of linear and mixed-signal integrated circuits.

Silicon Craft today has succeeded in gaining more than 20 international customers on chip design and solutions from Australia, USA, Europe, and Japan. Majority of employees earn engineering or related degrees from leading Thai and international universities. There are 65 active employees at SIC, almost half of them having master degrees or PhD (M. Thamsirianunt, personal communication, July 25, 2013). SIC provides scholarship to potential students in leading microelectronic departments of universities and later recruited them as its employees.

In the early stage of firm's establishment, the idea of IC design in Thailand was considered as high risk and far-fetched ambition. It was very difficult for co-founders to persuade local investors to jump into this business. The strategy was to spin-off from research organizations to be technopreneurs. Mr. Manop, therefore, decided to leave TIDI and set up his own IC design company with other co-founders. Some co-founders continued their works as university professors, while some worked as full-time directorship at SIC.

In the first six months, his new company had hardly any customers, as customers were not familiar and trust Thai IC designed company. Second strategy is therefore to get Thai technological and IC design capabilities being recognized in domestic and international market. The companied painstakingly focused only on IC design to

develop chip products to be sold to reputed international customers. This strategy proved a success. Silicon Craft developed application-specific integrated-circuit chips used in electronic devices and radio-frequency identification (RFID) chips that were sold in many countries. The company came to be internationally recognized as a chip provider.

Public procurement from NECTEC to develop smart RFID chip used for animal ID, which SIC claimed to be the world's tiniest chip with the lowest price, can be seen as an important 'learning event' of the company to gain technological and innovative capabilities. SIC also received financial investment from One Asset management, a leading Thai venture capitalist, for this IC design development.

Strategic-wise, SIC conducts its technology road mapping for segmenting new technologies and markets based on performance, application, and users. SIC keeps benchmarking its products' performance with world IC manufacturers like Philips, Texas Instruments, and EM Microelectronics. Currently, all of the company's chip products are exported. Nonetheless, after a long period of marketing effort, local customers began to show interests.

On external collaboration, co-founders at SIC play very active roles to engage with other stakeholders particularly with science, technology, and innovation supporting agencies in Thailand. For example, Mr. Manop chaired an executive directorship at a public organization, Software Industry Promotion Agency (SIPA) between 2007 and 2008. He and other co-founders, together with other developers and academics also established Thai Embedded System Association (TESA) as a knowledge-sharing and business-opportunity-development platform for new RFID startups since 2005.

SIC's future vision is to be one of the top five chip brands in the global RFID field and then be listed in Stock Exchange of Thailand.

5. Cross-case Analysis

According to finding from the case studies, there are five areas of observations - 1) product and process technology, 2) human resource management, 3) infrastructure and business environment, 4) capital and finance, and 5) linkages and spillovers.

5.1. Product and Process Technology

All firms were able to meet international requirements on quality and inventory control, and maintenance systems. This is a prerequisite for entering global semiconductor production networks. For the IC packaging companies, adapting machinery and equipment, process layout, and inventory and quality control systems are means for incremental innovations, while ODM like HM has already leveraged its innovation capability to engage with a development of project and process technology either on design technology or turnkey product for sophisticated clients. Government supports or grant for the EMS may be too little and too slow. Nonetheless, it is proved to be very valuable for IC designed company like SIC to kick off its technological innovation development. A significant level of technological upgrading, particularly on process technology can be seen among the EMS, the main reasons are that their facilities were inundated when the central part of Thailand suffered with severe flood in 2011. New machineries have been installed, while the simple IC productions were cancelled. Therefore, external factors can be important 'learning event', if firms have enough will and suitable strategies. Sufficient human capital supply in the country and advanced technological collaboration with buyers and suppliers are also important key ingredients for technological upgrading.

5.2. Human resource management

Overall, a demand on well-educated human resource in microelectronics is increasing, while the universities and vocational schools cannot supply firms with sufficient number of capable engineers and workers. According to interviews, IC/VLSI design and sensors product development work are increasing as Thailand still retain a reliable partnership status among international clients. As a result, these three firms will require more R&D personal in the near future. Apart from SIC and TMC which are actively engaged with R&D, HM is another ODM that plans to review its expansion of R&D department according to an increasing demand on higher technological product and process solutions. All firms start to emphasize not only on problem solving and on-the-job process learning skill, but also more 'systematic' and

‘formal’ training. TMEC is a good example of how public research institute can play an important role in advanced technological training for private firms.

5.3. Infrastructure and Business Environment

All firms require appropriate business environment. Educational and logistic infrastructures in Thailand are not the biggest concerns among the EMS, but flooding. Most of the EMS facilities are located in Autthaya, Pathumtani, and Chachoengsao, the provinces that heavily suffered from flooding. Firms and their clients require more commitment from Thai government to tackle this issue in order to gain trust and leverage the potential investment in the future. Toshiba even decided to move its facilities to Prachinburi, an Eastern province along the gulf of Thailand, instead. In term of technological development for competition, case-studied firms tend to strategize their innovation and technological development to serve demand and requirement of their original brand manufacturing (OBM) clients, rather than trying to be their competitors. This demonstrates a limit of upgrading in global industries like semiconductor.

5.4. Capital and Finance

While well-established firms tend to seek their funding by listing their companies at Stock Exchange of Thailand (SET), TMC has been heavily relied on public funding. The public funding and venture capital are main sources for startups like SIC.

5.5. Linkages and Spillovers

Apart from TMC, all four firms have closer linkages with their international clients, mainly from USA and Japan. While, NECTEC, in the past decade has slowly built up linkages with new startups specialized in microelectronic design. Though rather exceptional, some of its researchers have moved to be technopreneurs like the owner of SIC. After starting a new company, close collaboration with this public research institutes has been maintained.

The cross case comparison can be summarized in Table 7, which highlights differences and similarities in term of 1) core competencies, 2) key technologies, 3) innovation, and 4) linkages & collaboration.

Table 7: Core competency, technological capability, innovation and linkages

	Hana Semiconductor	Toshiba Semiconductor	Stars Microelectronics	TMEC	Silicon Craft Technology
Core competency	IC assembly solution and test services	Operation under standardized production process, requirements, and financial support from its parent company	Advanced EMS for MMA, IC packaging and testing	-	High-value added features and systems performance microchips.
Key technologies	Miniaturized IC design and process engineering	Absorptive capability on technology transfer from parent company	Process design, and tailor-made manufacturing technique	Submicron technology	IC Design Technology, Manufacturing process design
Innovation					
Type	Product & Design	Product & Process	Process/ problem solving	Product	Design & Product
Incentive	Cost/ sophisticate demand of clients	Upgrading and production plans from parent company	Exclusive demand from clients	Establishment of upstream semiconductor industry in Thailand	Techno-preneurship/ international competitiveness
Barrier	Sufficient capable R&D personnel/ PLC/Natural disaster	-	Cost efficiency, natural disaster	Capital/ Red tape/ TLC	Attitude among local client towards Thai IC design capability
Collaboration	Machinery suppliers, international clients	Work closely with regional company in Singapore	Process design with clients, and technological learning with supplier	Mainly higher educational institute, local start-up and public agencies	International client, TESA, subcontractor manufacturer in India and China

Source: Authors' compilation.

6. Conclusions

Thailand's semiconductor industry accounts for one quarter of total electronics exports. It has been dominated by MNCs from Japan and Singapore in particular. However, collaboration and networking among semiconductor firms in Thailand has been very limited. The industry is characterised by passive technological learning by firms.

Nonetheless, our case studies demonstrate that some local companies did upgrade from OEM to ODM activities. IC packaging is the key activities while some firms are actively engaged with IC design. There is also an emergence of a local fabless design-intensive company capable of serving demanding global customers. Public research institutes can play crucial roles in establishing such companies through human mobility. Their public procurement can also create learning event leading to major upgrading. This study also illustrates that crises can trigger a major change and upgrade position of a company in a global value chain, if such a company has accumulated the capabilities to make the shift.

In addition, we found that R&D tax incentives are necessary, but not sufficient conditions for technological upgrading in firms. Intermediary agents play a critical role in firm-level upgrading. In Thailand a division of labour has emerged among the intermediary agents. A sectoral promotion agency, namely, the Thai EEI provided overall sectoral policy framework and master plans for long-term development of the industry. A public research institute like NECTEC offered 'specific' technological and management training, necessary grant and equity investment. It could serve as the first and 'captive' market for innovative products. Lastly, an industrial association such as TESA facilitates networking formation, building trust among key players, business development, specific technical standard agreement, and training.

Drawing from the empirical evidence, we recommend that the Thai government launch strategic policies aimed at strengthening the upstream industry of semiconductors. The government should also consider providing incentives beyond tax especially for starting upstream companies and upgrading design and R&D capabilities of existing local firms. In addition, the issue of division of labour between different types of intermediaries are also critical for industry upgrading. Activities of some types of intermediaries should not only focus on providing consultancy, testing and training for downstream and standard production capabilities. It should encourage knowledge flow and capability building activities between local suppliers and transnational corporations.

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