The Challenge of Technological Upgrading: The Development of Integrated Circuits Manufacturing in Malaysia, and Thailand

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Abstract: The redeployment of export-oriented production by giant Multi-National Corporations (MNCs) expanded the contribution of integrated circuits manufacturing in the economic development of Malaysia and Thailand since the 1970s and 1980s respectively. Giant integrated circuits (IC) firms and industrial component firms (e.g. disk drive and electronics components for the automotive industry) dominated MNC relocation to Malaysia and Thailand since the early 1970s and late 1990s respectively. It also offered both countries the opportunity to connect with global value chains to enable exports of high tech products. This paper seeks to analyse the extent of technological upgrading achieved in the IC industry following an increasing shift in MNC strategies to upgrade to modular production systems. The evidence shows that significant widening and deepening has taken place in both countries, especially since the MNCs began upgrading their assembly and test plants in the host countries and host-site institutions responded to upgrade the embedding high tech infrastructure. Albeit institutional change in both countries have not been effective enough to stimulate massive technological catch up and leapfrogging *a la* South Korea and Taiwan, the evidence shows that a combination of policy initiatives, networking between MNCs, and national firms and support organizations have spearheaded technological upgrading in the industry. However, significant efforts must be taken to strengthen the high tech infrastructure to stimulate IC firms' participation in new product development and other frontier technological activities in both countries.

Keywords: Technological upgrading, IC manufacturing, Malaysia, Thailand

1. Introduction

Lall (2000) had argued that economies integrated in global value chains of rapidly expanding industries and at the same time evolved technological capabilities enjoyed rapid economic growth, while economies that did not evolve technological capabilities became losers in the globalization process. Examples of such a glowing account can be seen from exports of ICs, which formed a major plank behind investment and employment growth in China, Malaysia, Philippines, Singapore, South Korea, Taiwan, Thailand and Vietnam. Malaysia is the second largest exporter of IC products from Southeast Asia after Singapore. Whereas large scale IC production in Malaysia began since the early 1970s, the industry grew strongly in Thailand from the 1980s (Rasiah, 2009).

Malaysia and Thailand have experienced a relative fall in the share of electronics exports in total national exports since the late 1990s (Rasiah, Yap and Chandran, 2014). While some IC sub-sectors contribution has fallen the main cause of the relative decline is a consequence of expansion in other sectors. Despite the significant changes in the structure of manufactured exports, the electronics industry is one of the key industries in the two countries, and hence, why these countries were picked up for analysis. Whereas intra-ASEAN trade accounted for around 20-25 per cent of Malaysia's electronics exports over the period 2000-2010 (Marko, 2015), only exports to Singapore from Malaysia have remained important among the market destinations of the three countries.

As has been argued by Hirschman (1970) and Amsden (1983), integrating with the global economy offers the opportunities for firms to enjoy the market size and flows of knowledge to support technological upgrading. While integration in global markets offers considerable opportunities for growth, countries that do not undertake proactive policies to effect the institutional change essential to support upgrading are unlikely to enjoy transformation from low to high value added activities.[1] Indeed, as the labour-intensive production stages, such as assembly and test experience a shift in production technology, sites unable to generate the requisite technical and creative labour force are expected to lose these stages to other sites.

In this paper we examine the extent of technological upgrading experienced by the IC industry in Malaysia and Thailand. The rest of the paper is organized as follows. We discuss the contribution of the IC industry to trade in Malaysia and Thailand in the next section, including the relative shares of IC exports from the two countries, which is then followed by an evaluation of changes in IC exports and their national export shares, as well as, their trade balances. This is followed by key theoretical conditions and subsequently the methodology and data used. Section 5 discusses the technological upgrading enjoyed in the IC industry in the two countries. Section 6 evaluates the drivers of the upgrading. Section7 finishes with the conclusions.

2. Importance of the Integrated Circuits Industry

The integrated circuits industry is one of the high technology industries that has shaped the Schumpeterian business cycles since the 1950s (Hoffman and Rush, 1984; Perez, 1985). Since Malaysia and Thailand did not have in place large domestic markets for the IC industry, both

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[1] The early advocates calling for institutional change to support technological upgrading are Veblen (1915) and Nelson and Winter (1981).

countries switched from import-substitution to export-orientation. Generous incentives, (which included tax breaks for exporting), dominated the early waves of production relocation by foreign firms (Rasiah, 2009). While the industry's nucleus, i.e. the microchip, has driven precision and control so as to support avionics, computers, smartphones, automotive products and a whole range of other industries, it has supported massive job creation directly and indirectly. Indeed, IC manufacturing was among the industries that underwent internationalization so that the labour-intensive industries were relocated in developing sites endowed with trainable labour, stability, security and good basic infrastructure (Lim, 1978; Scibberas, 1977).

Both nationally and internationally the IC industry has contributed significantly to the economies of Malaysia and Thailand. Indeed, both countries have enjoyed significant exports of IC products since the 1970s and 1980s.

World Exports

Malaysia and Thailand have been among the top 15 largest exporters of integrated circuits in 2010-14. Malaysia world export share rose from 6.3% in 2010 to 7.2% in 2014 (see Table 1). However, Thailand experienced a fall in world export shares from 1.9% in 2010 to 1.6% in 2014. Hence, despite a saturation in labour reserves, Malaysia has managed to expand its world export share through growth in capital-intensive fabricated wafers since 2005 (Rasiah and Yap, 2016).

Table 1: Export Share of World's Top Integrated Chips exporters, 2010 and 2014 (%)

	2010	2014
China a	13.0	17.2
Singapore	17.8	17.0
Chinese Taipei	12.6	13.8
Korea, Republic of	8.9	10.5
EU(28)	13.6	9.4
Extra-EU	4.1	3.8
United States	9.8	7.8
Malaysia a	**6.3**	**7.2**
Japan	9.8	6.4
Philippines a, b	3.4	2.8
Thailand	**1.9**	**1.6**
Israel	0.5	0.7
Mexico a	0.4	0.5
Vietnam b	0.1	0.5
Canada	0.4	0.3
Share in World Exports	**98.7**	**95.8**

Source: WTO (2015)

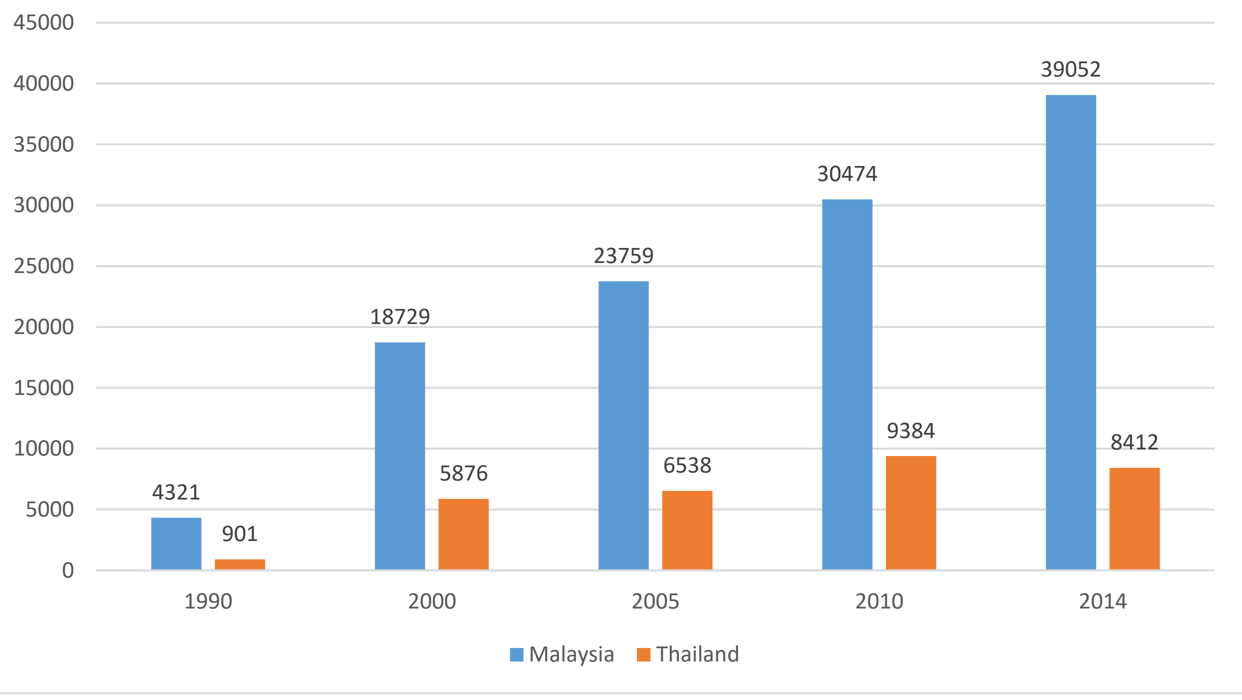
National Exports

We examine IC trade of Malaysia and Thailand. In addition to analysing exports, we also examine the share of these exports in overall national exports, and trade balance.

Growth in Exports

IC exports from Malaysia grew from USD 4.3 billion in 1990 to USD 39.1 billion in 2014, while from Thailand it grew from USD 0.9 billion 1990 USD 9.4 billion in 2010 before falling to USD 8.4 billion in 2014 (Figure 1). Exports of ICs from Malaysia grew dramatically in the period 1990-2014 well exceeding exports from Thailand. However, exports from Thailand declined in the period 2010-14.

Figure 1: IC Exports, Malaysia and Thailand, 1990-2014 (USD Millions)

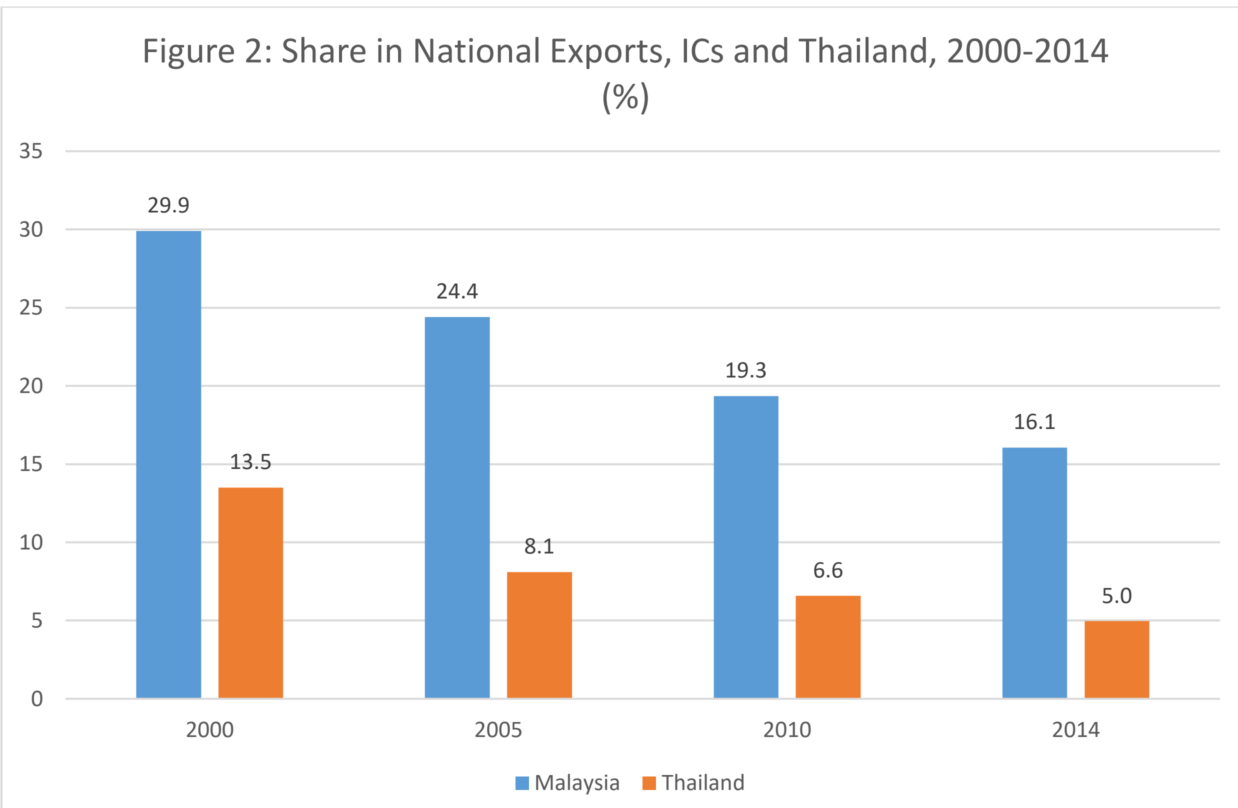


Source: WTO (2015)

Overall, Malaysia has maintained steady trend growth in IC exports but with slower growth achieved after 2000, while Thailand has experienced a decline in some sectors.

Share in national exports

As a share of national exports, Malaysia and Thailand have experienced a trend fall in the contribution of ICs over the period 1990-2014 (see Figure 2). Export shares in Malaysia and Thailand fell from 29.9% and 13.5% respectively in 2000 to 16.1% and 5.0% in 2014 respectively.



Source: WTO (2015)

Trade Balance

Malaysia's trade balance went negative between 1990 to 2010 before it became positive in 2014 (Figure 3). Thailand's trade balance remained throughout the period 1990-2014. While this account does not show the eventual balance after repatriation of profits have been accounted by foreign firms, it is useful to denote the IC current trade balance of these countries, which obviously only shows improvements in Malaysia.

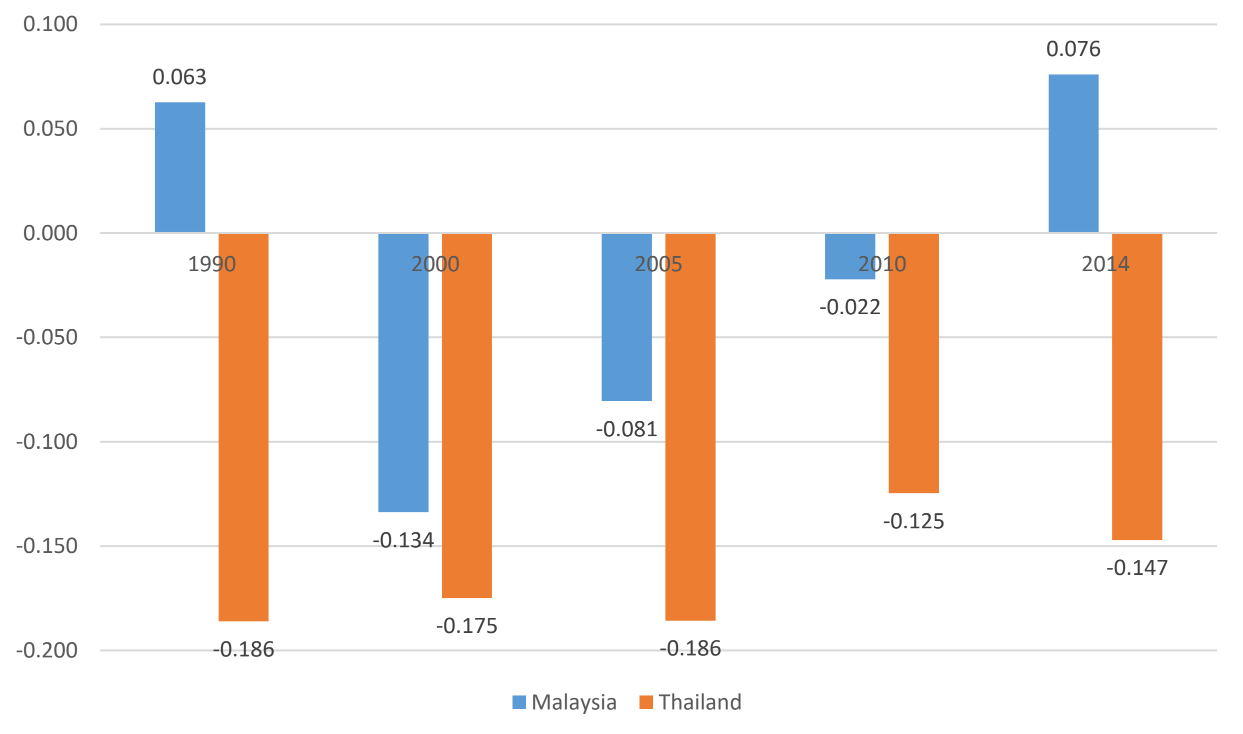


Figure 3: Trade Balance, ICs, Malaysia and Thailand, 1990-2014

It is clear that the IC industry not only has a long presence but also shows strong exports, though the trade balance of Thailand has remained severely negative. Malaysia's trade balance has become positive in 2014. Thus, the IC industry of the two countries offers useful example to examine the drivers of technological upgrading.

3. Theoretical Considerations

Four main strands of theoretical literature are reviewed here to put into perspective technological upgrading in the IC industry in Malaysia and Thailand. Firstly, the industry itself has undergone massive transition in knowledge terms. The second involves the advent of modularization in the industry, which has facilitated the outsourcing of knowledge-based stages of production to other firms. However, the nature of changes in the production relations in the IC industry has been significantly different from the automotive industry. The third relate to clustering, which requires the profound assessment of state policy.

The first addresses the rising importance of knowledge-based tasks in the IC industry. Increasing automation, including robotization, and demand for knowledge-based activities, such as designing and R&D, has shaped IC production at host-sites globally since the late 1980s. Indeed, by 2000 all IC manufacturing had become strongly capital- and knowledge-intensive so that technical, statistical and cognitive skills had become the major driver of employment (Rasiah, 2009). Even so engineering personnel have also become important as designing and the peripheral aspects of R&D are not handled by suppliers of components and parts. In addition, since the late 1990s, the industry has witnessed a new wave of automation with robotization becoming a major redefining the division of labour in the industry. A combination of rising wages for skilled labour but more importantly the increasing requirement for nano-precision arising from continuous miniaturization has made labour-shedding an integral feature of the industry.

While human capital is the key resource essential to support knowledge-based activities, organizational support through training and R&D labs, university-industry linkages and incentives (including R&D grants) are also important to spearhead technological upgrading in firms. Firms are increasingly seeking competent chip designers, software engineers, and chemical engineers and physicists to technologically deepen operations.

The second addresses the proliferation of modularization in the IC industry, which has offered opportunities for national firms at host-sites to participate in high value added activities, such as R&D and designing. Apple's effort to subcontract out such activities to its Taiwanese supplier (Foxconn) in China is an example (Sturgeon, 2002). Thus, foreign host-sites' capacity to retain IC production has very much depended on the extent of institutional change that has taken place to generate the human capital essential to support technological upgrading. While the connectivity and coordination expounded by Gereffi, Humphrey and Sturgeon (2005) offers significant room for stimulating technological upgrading, it is important that the key actors of a national or sectoral innovation system is evolved to stimulate such activities.

The third addresses the degree of clustering enjoyed by firms in particular locations. While clustering focuses on an agglomeration of firms and organizations in particular locales, as Ganiatsos et al (1998) have argued co-location of critical organizations and supplier and buyer firms will generate little cluster synergies. Hence, a high degree of connection and coordination is essential to support clustering activities. Rasiah (2007) used the term network cohesion or integration as being critical to spearhead effective clustering of economic activities.

Both the global value chain (GVC) and Global Production Networks (GPN) approaches are excellent in explaining the internationalization of production and the spread of value adding activities while others stagnate or fade away. Indeed, such approaches also fail to explain catching up and leapfrogging in the value chains. It is here that both approaches suffer from the shortcomings of neo-Marxist approaches owing the claim that the state is an instrument of the ruling bourgeoisie while the international division of labour is an institutional innovation of capital (Jenkins, 2002).

Meanwhile a new argument has attempted to fuse an old neoclassical explanation of factor endowments shaping differentiation of the international division of labour that was advanced by

Helleiner (1973) but sprinkling it with production sharing logic as the basis for the fragmentation and internationalization of production latter simply dismisses the relevance of state intervention in the operations of markets (Kondo and Kimura, 2011). The entire logic behind such an argument appears to be a reinventing exercise that puts old wine into new bottles. Indeed, the rationale is similar to what the neo-Marxists argue except that they differ in the causes and consequences of such developments. Whereas the neo-Marxist claim an exploitative motive by capital and a hellish consequence for the host-site agents, the neoclassical economists claim a sharing motive by capital and a heavenly consequence for the host-site agents.

The final theoretical argument comes from the role of the state. As advocated by the technological catch up advocators (e.g. Gerschenkron, 1952; Abramovitz, 1956) and the developmental state exponents, the state is a key instrument in engendering the conditions for accumulation at host-sites. That South Korean and Taiwanese firms were able to connect and catch up in global value chains was a consequence of capabilities evolved from government policies to support them effectively (Amsden, 1989; Chang, 1994; Fransman, 1986; Wade, 1990). Hence, we shall analyse technological upgrading in the IC industry in Malaysia and Thailand to examine the role of governments in both countries.

Taken together, the critical features of successful upgrading can be explained using Rasiah's (2007) systemic quad. The first two pillars refer to basic and high tech infrastructure, while the third and fourth refer to network cohesion and global integration. Infrastructure is differentiated because the nature of governance between basic and high tech infrastructure is significantly different as the latter relate significantly to the generation of knowledge. Basic infrastructure largely involve the provision of public utilities, while high tech infrastructure is associated with the provision of public goods. The simultaneous promotion of these pillars through strong government intervention is a *sine qua non* for successful technological upgrading.

4. Methodology and Data

Given the nature of the study, we first identify the capabilities amassed, and use case studies to capture the strategies firms have used to upgrade technologically in the IC industry. The focus is on firms equipped with the highest capabilities so as to identify the drivers behind them, and that is why we have picked up case studies from the leading exporters from Malaysia and Thailand. Secondary materials have also be accessed from manuals, reports and publications related to the evidence required. We identified the lead firms from Gartner (2012a) and Gartner (2012b) and the national electronics industry associations.

Information on technological capabilities of the firms was obtained from company websites, as well as interviews. We then interviewed managers and managing directors from these firms to identify the factors that drove technological upgrading, or the relocation of high value added activities in Malaysia and Thailand. Owing to the confidentiality of the study, no interviewee is revealed in this paper.

The interviews were carried out over 11 years because of the difficulty associated with establishing contacts with the managers and managing directors. We included two retired Vice Presidents and three managers from Intel, three retired managers of Advanced Micro Devices, which was acquired by Mubadala Corporation later, two managers from Renesas, one manager from Seagate, one manager of ST Microelectronics, and one manager of Infineon. In total we carried out interviews with 31 managing directors and directors from 12 integrated circuits firms with operations in over two countries (see Table 2).

Table 2: Officials Interviewed, 20052016

	Firm	Number of Officials	Locations	Main business
1	Freescale	3	Petaling Jaya	ICs
2	Global Foundries	5	Penang	ICs
3	Hana Semiconductor	1	Bangkok	ICs
4	Infineon	1	Kulim	ICs
5	Intel	7	Penang	ICs
6	Renesas	3	Penang	ICs
7	Samsung Semiconductor	1	Kuala Lumpur	ICs
8	ST Microelectronics	2	Johore	ICs
9	Texas Instruments	3	Kuala Lumpur and Penang	ICs
10	Toshiba Semiconductor	1	Bangkok	ICs

Source: Authors' interviews, 2005-2013

The case study methodology was chosen because of the in-depth insights it offers, especially on particular decisions made for to upgrade from national capabilities or relocating high technology operations abroad (Bryan, 1964; Hanbrick, 1983; Thomas, 1982; Dyer and Nobeoka; 2000; Langlois and Steinmuller, 2000; Best, 2001; Karnani, 2007; Inkpen, 2008). While detailed case studies lack statistical rigor and generalizability, they offer the best accounts of complex strategies adopted by firms, organizations and individuals. As pointed out by Doyle (2003: 326), interviews with the firms involved were preferred over gathering large datasets for statistical analysis because the purpose of the study was interpretive rather than predictive. Indeed, interviews offer the best primary source of information gathering to establish the strategies pursued by managers. To reduce the problem of exaggerations by the respondents, the information was then checked wherever possible with the secondary sources from the national electronics associations, electronics journals and Gartner (2012a; 2012b).

Interviews with officials of the national electronics associations showed that there were no nationally owned lead firms in the IC industry in Malaysia and Thailand. Hence, the target group in this study are three sets of firms, foreign MNC subsidiaries of lead firms, modular contract manufacturers, and other contract manufacturers. Using the global value chain framework advanced by Sturgeon (2002), Gereffi, Humphrey and Sturgeon (2005) and Sturgeon and Murakami (2010), we identified lead firms in IC industry as shown in Table 3. By this classification, there are largely three types of linkages involving IC firms operating in Malaysia and Thailand. These types are: one, MNC subsidiary linkages; two, contract firms that undertaken considerable designing and R&D in the components and completely knocked down parts they produce; and three, firms that simply only assemble parts for export. The IC industry supplies components to all other IC industries, including Texas Instruments and Freescale to the military and aerospace industries. However, no lead firms in the military and aerospace industry are found in Malaysia and Thailand. Where lead firms are operating in the three countries, they are not dominant in the value chains as control is held in the hands of parent plants abroad.

MNC subsidiaries of lead firms: The first are subsidiaries of lead MNC firms that undertake assembly of components and CKDs for their parent plants abroad. Intel undertakes the assembly of microprocessors in Malaysia, while Texas Instruments, Freescale and Infineon are engaged in the assembly of memories, logic and power chips. Infineon and Osram undertake wafer fabrication in Malaysia. The subsidiaries carry out considerable amount of designing in both countries. The same is reported by Seagate in Thailand.

Of the three countries, MNC operations in the IC industry is most sophisticated in Malaysia where both supportive R&D, designing and wafer fabrication activities are carried out. However, the lack of human capital has restricted the potential for further expansion of these activities in Malaysia.

Seagate and Toshiba are other MNCs whose subsidiaries are located in Thailand to undertake disk drive assembly and automotive components respectively. Dell used to assemble computers in Malaysia but has ceased such operations a few years ago.

The prime linkage for the national economies from their activities are employment, income generation opportunities and learning through working in the firms. Buyer-supplier relationships between the MNCs and national firms in machine fabrication, tooling and plastic injection moulding grew in the 1980s and 1990s in Malaysia (Rasiah, 1994, 1995). However, such activities have declined since the end of 1990s owing to production shift by MNCs to China, and the lack of designers in the country.

Modular contract manufacturers: Sturgeon (2002) advanced the influence of modular value chains in which lead firms contract out designing and R&D of particular components and CKDs to suppliers (e.g. Apple to Foxconn). Significant opportunities for technological upgrading exist in modular chains as the suppliers undertake designing and R&D activities of the components or CKDs they produce. Both national firms and contract MNCs subsidiaries are engaged in such activities in sub-industries with varying intensity of technological sophistication, such as PCBs, FCBs, motherboards, monitors, and components (including ICs). Examples of such firms among the three countries include: Malaysia - Globetronics in ICs, Vitrox in optoelectronics, Silterra in wafer fabrication; Thailand - Hana Microelectronics (HM), Stars Microelectronics Thailand (SMT) and Silicon Craft Technology some of such firms in Thailand who have upgraded to participate in modular value chains. The latter is further assisted by institutional support through grants from the government in the two countries.

Other Contract manufacturers: While there is certainly a shift to modular operations, the bulk of the contract manufacturers in the two countries operate as contract manufacturers without significant participation in designing and R&D activities. Several national and foreign subsidiary firms produce PCBs and FCBs, and resistors, capacitors and LEDs with little designing and R&D activities. Over 200 national and joint-venture firms are engaged in PCB, FCB and other component manufacturing activities that are either exported or sold in Malaysia and Thailand to lead firms (Rasiah, 2009, 2016; Patarapong, Chairatana and Chayanajit, 2016). While considerable adaptations take place in these firms they do not have a profound presence of R&D staff and a department to undertake designing and R&D activities.

Table 3: Main IC Products and Lead Firms

Category	Products	Lead firms
Integrated circuits	Microprocessors, microcontrollers, memories, logic chips	Intel, Samsung, TSMC, Texas Instruments, Toshiba

Source: Adapted and expanded from Sturgeon and Kawakami (2010)

5. Technological Upgrading

In this section we analyse the stage of operations technologically of firms in the IC products in Malaysia and Thailand (Table 4). The firms studied in the two countries are the MNC subsidiaries and national contract firms operating in Malaysia, including suppliers. Since the focus of the study is on explaining the drivers of upgrading the most technologically sophisticated firms were selected based on interviews with officials of the national industry associations and those willing to participate in the study.

Since the lead firms most sophisticated operations are not in Malaysia and Thailand, the assessment is carried out on their subsidiaries and MNC contract firms, and national contract firms that have operations in these countries. Intel, ASE Electronics, Texas Instruments, Renesas, and Infinion are MNCs with Leading edge operations in Malaysia, while Toshiba undertakes similar activities in Thailand. Intel, Texas Instruments and Renesas undertake supportive R&D and chip design activities in Malaysia using cutting edge technology. ASE electronics assembles ICs in Malaysia with strong supportive R&D activities. Toshiba also has strong supportive R&D activities in Thailand.

Among national contract firms, Globetronics operates as an original equipment manufacturer assembling chips in Penang. Meanwhile, Carsem and Unisem have internationalized their operations with subsidiaries in Europe. These firms also have Original Design Manufacturing (ODM) capability. Hana Semiconductor and Star Microelectronics Technology undertake similar activities in Thailand with a major focus on supplying automotive firms. All firms studies have upgraded to between level 4 and level 5 activities using the typology from Rasiah (2017).

Table 4: Multinational subsidiaries and contract, and National contract firms, IC Industry, Malaysia and Thailand, 2016

Category	Lead firms	MNC-subsidiaries and contract firms	National contract firms
Integrated circuits	Intel, Samsung, TSMC, UMC, Texas Instruments, Renesas, Freescale, Infineon, Toshiba	Intel, ASE Electronics, Renesas, Infinion, Toshiba	Globetronics Carsem Unisem, Hana Semiconductors, Star Microelectonics, Technology

Source: Author

While lead firms have manufacturing and technological upgrading activities, national firms too have upgraded significantly to participate in supplying fairly high value added activities in the IC value chain in Malaysia and Thailand. In the next section we discuss the drivers of such upgrading.

6. Drivers of Upgrading

The entry of IC production on a large scale to Malaysia and Thailand began during the labour-intensive phase of assembly and test operations in the 1970s and 1980s. It is important to note that the initiation of the IC value chains to connect Malaysia and Thailand began with the operations of the MNCs who responded to responses by national governments to develop good basic infrastructure at defined locations where customs and transport, and labour movement to work coordination could be undertaken smoothly. Export processing zones, thus proliferated in these countries primarily to attract IC manufacturing for export. However, following the introduction of robotization and flexible production systems knowledge-based chip assembly began to relocate out of Malaysia and Thailand from the late 1990s. Both Malaysia and Thailand have managed to retain significant activities but the extent of production expansion in such activities has declined since 2000 as the demand for specialized technical personnel rose beyond the capacity of domestic human resource policies to meet them. Also, cheaper technical labour have attracted major assemblies to Szechuan (China) and Vietnam.

The IC industry has undergone two major technological developments in Southeast Asia over the last 15 years (see also Rasiah, Yap and Yap, 2015). Semiconductor manufacturing activities that have remained in Malaysia and Thailand have either largely upgraded or have downgraded into the manufacture of printed and flexible circuit boards, disk drives and passive components using low skilled foreign labour. The first relate to a shift to designing and supportive R&D, which started of strongly since the 1990s among semiconductor firms. The second relate to the expansion into downstream low value added assemblies, such as printed circuit boards (PCB) and flexible circuit boards (FCB) using large numbers of less skilled foreign workers. Interviews with the 5 foreign MNCs, and 6 national firms show a pattern that has emerged owing to a lack of effective human capital development policies in Malaysia and Thailand. The increased deployment of less skilled foreign labour since 2005 has revived growth in the industry but with a specialization in low value added activities. Even semiconductor firms that have retained assembly and test operations in Malaysia have increasingly hired less skilled foreign workers. Based on the statistics gathered by the Department of statistics, foreign labour accounted for almost 35 percent of operators in the semiconductor industry in Malaysia in 2013.[2] We examine the drivers of major technological changes that has affected semiconductors production in the two countries.

Malaysia

Intel and Motorola have established designing centres in Penang, while Freescale is planning to build one in 2017 in Selangor. In addition, The sale of the entire list of wafer fabrication plants in 2009 by Advanced Micro Devices further reduced its interest on R&D. Texas Instruments acquired Fairchild (which was acquired by National Semiconductor earlier), which expanded its operations following the takeover, also reported the termination of plans to deepen R&D operations in Malaysia. This firm still assembles and tests integrated circuits in Malaysia but on a smaller scale.

Unlike the experience of Intel and Texas Instruments in Penang, the lack of adequate supply of designers and technical human capital has driven an American firm in Selangor to limit operators to simpler tasks to coordinate the highly automated operations on the shopfloor.[3] Consequently, the reduced demand for technical knowledge of the direct workers has allowed this firm to hire less skilled foreign workers. Hence, while the operator in the Penang firms have integrated the knowhow of technicians, maintenance foreman and operators to function as a highly technical node in the production line, the Selangor firm has separated the two functions with the engineers increasingly required to undertake designing while the operators confined to operating automated machines. A senior engineer from this firm reported initiating plans to build a designing centre to support its operations in Selangor, Malaysia.[4]

Nevertheless, considerable automation and the introduction of continuous improvement work practices (*kaizen*), which has since the 1990s led to the substitution of dexterous skills with cognitive, technical and statistical skills since the 1980s in the semiconductor firms (see also Rasiah, 1995), the two American and one Japanese MNCs still undertake adaptation activities, especially in production organization and processes. Rasiah (2010) had reported the proliferation

[2] Unpublished data supplied by the Department of Statistics (DOS), Malaysia.
[3] Interview by Rajah on 25 April in Kuala Lumpur.
[4] Interview by Rajah on 25 April in Kuala Lumpur.

of total preventive maintenance and total quality management processes in 9 semiconductor firms. Process engineers in one of these firms even adapted the Electron beam induced current (EBIC) in 1990 that allowed massive magnification capabilities so as to assist back-end activities by strengthening their failure laboratory analysis before packaging is of the chips are carried out. All levels of workers in the two semiconductor firms were reported by their officials as numerically equipped with strong technical skills. Although less spectacular, the single national firm engaged in semiconductor operations in our study also reported similar developments on the shopfloor.

Linkages between foreign IC firms and national firms appeared promising since the 1980s when demand for proximate sourcing increased (Rasiah, 1988, 1989). Indeed, significant supplies of precision tools, semi-automated machinery and fabrication opportunities were established between MNCs and national firms in Penang over the 1980s and 1990s. However, national suppliers were unable to sustain their upgrading activities as the demand for knowledge-based activities rose further. National suppliers were not able to upgrade into designing and R&D activities due to a lack of human capital supply in the country, and weak university-industry R&D linkages (Rasiah, 2010).

Also sporadic university-industry linkages have emerged between foreign multinationals and national universities. While the previously strong linkage that existed over the period 1978-1996 between Universiti Sains Malaysia's innovation centre and IC firms in Penang on the development of undergraduate courses in engineering and computer science have declined, engineers from these firms have continued to work with academics in the national universities on an *ad hoc* basis. Also, government grants, such as the Long Run Grant Scheme (LRGS) administered by the Ministry of Higher Education (MOHE) and the Techno Fund coordinated by the Ministry of Science, Technology and Innovation (MOSTI) explicitly encourage university-industry linkages (Malaysia, 2016). Indeed, the provision of such grants has helped Malaysian universities to raise significantly publication in scientific journals and file patents (Rasiah and Chandran, 2015). However, interviews with the firms show that researchers at national universities have been reluctant to carry out what is at firms' disposal thereby making such links marginal to their operations.

The government attempted to participate directly to support technological upgrading in the IC industry when it launched the Malaysian Institute of Microelectronics Systems (MIMOS) in 1985. MIMOS was moved from the Prime Minister's department in 1993 and corporatized. Despite attempts to attract participation by MNCs, MIMOS has only managed to develop its own technologies for the launching of national firms. Among its achievements are the creation of the national wafer fabrication plants of Silterra and 1st Silicon (sold later to X-Fab). The latter was later sold to a foreign firm called X-Fab (Yap and Rasiah, 2016). Silterra is a foundry engaged in the fabrication of Complementary Metal Oxide Semiconductor (CMOS) wafers. While the firm has R&D and designing operations, it is very much at the bottom of wafer fabrication plants by market shares in the world (Yap, 2015).

Following the launching of the Way Forward blueprint in 1991, the government set up the Human Resource Development Council (HRDC), the Malaysian Technology Development Corporation (MTDC), Multimedia Development Corporation (MDEC), and Malaysia Industry-Government High Technology (MIGHT) in 1993, and the Multimedia Super Corridor (MSC) in 1995 support structural transformation of industry from low to high value added activities. The HRDC, which collects 2% of payroll from firms with employment size 50 and above that the firms can claim only through approved training expenditure, has been reported to have stimulated an intensification of training among industrial firms in Malaysia. However, the remaining organizations created have yet to produce significant results (Rasiah, 2011).

While grants to support R&D were began when the Action Plan for New Technology Development was launched in 1991, take up was originally confined to Silterra among the IC firms. Interviews showed that the government had favoured Bumiputera firms at that time. Grants were then extended to foreign firms after 2005, which led to Intel, Osram, Infineon, Dell and Agilent among others to obtain grants to participate in wafer fabrication, and chip design activities (Rasiah, Yap and Yap, 2015). Collaboration Research in Engineering, Science and Technology (CREST) was subsequently formed in 2012 to strengthen R&D collaboration between universities, government and industry.[5] Using government grants, CREST finances approved R&D that is then carried out in universities and firms to support new innovations jointly developed universities and firms. Its members in April 2016 included Alterra, AMD, Avago, Clarion, Intel, Motorola Solutions, Osram, Bose, National Instruments, Keysight Technologies, and Silterra. However, the capacity of CREST to widen and deepen R&D activities to support technological transformation in the the IC industry very much depends on its capacity to sustain government funding, attract participation by firms and universities, the reinvigoration of existing related supporting organizations, and an expansion of the requisite human capital in the country. One national firm, which did not wish to have its name disclosed, noted that they located their chip designing activities in Singapore because of the grant given by its government.

Thailand

Generous incentives from the Board of Investment (BOI), especially related to tax holidays and tariff-free operations attracted the first major agglomeration of IC assembly and test operations in Thailand since the 1980s. Since the 1990s the Government promoted technology diffusion and innovation. The National Science and Technology Development Agency (NSTDA) established the Industrial Consultancy Services in 1992 to promote the use of local and foreign technical consultants and facilitate the formation of alliances (UNCTAD, 2005). NSTDA launched Software Park Thailand to stimulate innovation in startup firms. The BOI also developed the Unit for Industrial Transfer of Technology 2 Linkage Development (BUILD) programme to strengthen linkages and help small and medium-sized contract manufacturers improve their productivity and facilitate cooperation between foreign and domestic firms. It is estimated that about $148 million worth of transactions took place in BUILD in 2001 (UNCTAD, 2005: 2).

However, without R&D grants, Thailand lacked sufficient interventions to solve collective action problems in critical areas, such as in designing and R&D in the development of integrated circuits. Recognition the lack of upgrading, the Thai Embedded Systems Association (TESA) was founded in 2001 by group of academics and local private industrialist in as a forum for developers and technology users in the field of embedded computing technology to coordinate their activities. This initiative emerged following efforts by the Ministry of Industry to launch the Thailand Electrical and Electronics Institute (EEI) in 1998 to check a slowdown in the IC industry. Inter alia, TESA

[5] Interview conducted by Rajah on 12 December 2015 in Georgetown.

has started a platform to train university students to handle embedded electronic systems, which interviews show have largely been successful especially in the development software systems for automotive components. These programs have the support of a wide network of members that include IC firms, universities and customers and by 2015 had developed eight technology roadmaps related to the embedded systems industry for three ministries, provided testing services and certified electronic products, and matched new start-ups with investors (Patarapong, Chairatana and Chayanajit, 2016).

In addition the BOI exempted import tariffs from wafer fabrication firms in August 2004, though there has been no relocation of foreign wafer fabrication plants to Thailand. This is because wafer fabrication is highly capital-intensive that involve lumpy upfront capital investment. The lack of grants to attract such activities, and research universities are the main reasons why wafer fabrication has yet to emerge in Thailand (Rasiah, Yap and Yap, 2016). Hence, labour-intensive operations in activities, such as disk drive assembly still dominate IC exports from Thailand.

The lack of adequate supply of technical and engineering human capital, the absence of R&D grants to stimulate designing and R&D, and the lack of electronics-based research in universities and other laboratories drove out American chip manufacturing from Thailand from the 1980s (Rasiah, 2009). Thailand became a major platform for the assembly and test of automotive-based IC design, and industrial and consumer electronics products and disk drives from the late 1980s. Nevertheless, substantial technological upgrading from acquisition by MNCs and learning by doing has enabled improvements in process technology in Thailand (Hobday and Rush, 2007). In addition, some amount of designing, including in IC-related automotive systems, have emerged in Thailand as some MNCs have established collaborative links with the Universities of Chulalongkorn, Mongkut University of Technology Ladkrabang (KMITL) and Chiang Mai University (Patarapong, Chairatana and Chayanajit, 2015: 11).

The founding of the Hard Disk Drive Institute (HDDI) helped provide scientific infrastructure for the HDD industry by establishing a central laboratory and networks of government laboratories. Because the HDDI was created with strong support from the HDD manufacturers it functioned well as a resource provider and a broker because it could understand the rapidly changing HDD technologies in manufacturing. The HDDI was initially managed by a steering committee comprising representatives from NECTEC, BOI, the Ministry of Industry (MOI), the Asian Institute of Technology, Thammasat University, and four major HDD manufacturers (Intarakumnerd and Chaoroenporn, 2013).

Both MNCs and national contract manufacturing IC firms still operate in Thailand. Although MNCs hardly undertake core R&D activities in the IC industry in Thailand preferring to utilize their capabilities from parent locations (Hobday and Rush, 2007), they are engaged in intensive incremental engineering activities, including designing. With 16,400 employees, (which manufactures hard disks), was among the largest employers in the IC industry in Thailand in 2015 (Reuters, 2015). Seagate has capabilities to design and re-engineer machinery and equipment in the subsidiaries in Thailand. Toshiba Semiconductor Thailand participates in incremental engineering activities, especially in adapting machinery and equipment, through small group activities and quality control circles.

The national firms, Hana Semiconductor (HS), Stars Microelectronics Thailand (SMT) and Silicon Craft Technology for example began designing of customised IC packaging (Patarapong, Chairatana and Chayanajit, 2015: 14, 17). Hana acquired the Ohio (United States) factory of S-Vision in 1999, which provided the firm with the technology and facilities needed to assemble the “video monitor on a chip” for reflective "liquid crystal on silicon" micro displays (UNCTAD, 2005: 24). This allowed HM to produce micro displays, which have a high potential as a key component in large-screen television and computer monitors, multimedia projectors, viewfinders for digital and video cameras, and video headsets and handheld devices.

HM and SMT have also evolved capabilities to train their suppliers, and fresh graduates from Thai universities. National firms have also established innovation research linkages with Thai universities to support upgrading in the firms through the National Electronics and Computer Development Center (NECTEC), though, the scale of their support is not comparable to the synergies evolved in Taiwan. Interviews with a Thai expert from a national firm showed that Thai firms are technologically inferior to IC firms in South Korea and Taiwan because of the lack of cutting edge R&D facilities in the country.[6] Indeed, research conducted in Thai universities are not at the technology frontier of IC production.

Overall, both MNCs and national contract producers have upgraded to OEM and ODM activities, and a number actually undertake R&D activities in-house as well as through links with consortiums and linkages with high tech parks and universities. Such developments have been driven largely by national governments support through the provision of grants, incentives and science and technology parks, as well as promotion efforts by the related ministries. That national firms have not reached the technology frontier is only because the requisite human capital, research support from world class semiconductor specialization universities, and strategies to acquire leading but ailing wafer fabrication and chip design firms during times of crisis to leap sufficiently ahead to organize a catch up and leapfrog in the industry. The government was instrumental in Samsung’s and TSMC’s catch up and leapfrog through mergers and acquisitions.

7. Conclusions

The IC industry has been a major contributor to exports and employment in Malaysia, and Thailand. While the significance of the industry to the national economy has fallen slightly since the late 1990s, they have remained important in Malaysia and Thailand. At the firm level some firms integrated functional activities such as designing and R&D, albeit primarily in the proliferation of older technologies, and in incremental engineering activities.

Government in both countries set up meso-organizations to stimulate firms participation in training, precision testing, designing, and R&D activities, including science and technology parks, and platform for raising university-industry linkages. In doing so, business associations, sectoral (in Malaysia), apex (Malaysia, and Thailand) and foreign organizations (Malaysia) have played important roles to coordinate links between firms and government agencies to solve collective action problems.

[6] Interview in Bangkok.

While considerable upgrading has sustained IC exports from the three countries, the evidence shows that IC firms in Malaysia and Thailand have yet to progress extensively into new product development, and participation in frontier R&D activities. Little wonder that firms in these countries are still far from the technology frontier, which is also why productivity growth in the industries in these countries have slowed down (Rasiah, 2010; Patarapong, Chairatna and Chairajit, 2016). MNCs still dominate the most sophisticated technological operations in both countries.

Clearly, further technological upgrading is necessary to sustain IC exports from Malaysia and Thailand and this can only be achieved through a major revamp in education and training organizations, and upgrading of research support at universities and public laboratories to produce the human capital essential to lead such a transformation. Business associations can play a key role in this to ensure effective connectivity and coordination is established between these organizations and firms to steer further upgrading. Also, while grants and other financial incentives are essential to stimulate participation in designing and R&D by the government, effective mechanisms to evaluate *ex ante*, monitory and appraise *ex-post* the carrots are important to check their dissipation. The developmental state that drives an institutional change to spearhead catching up and leapfrogging is essential to ensure IC firms in Malaysia and Thailand move up the value chain.

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